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**Sexton et al.**

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(45) **Date of Patent: *Jul. 24, 2012**

(54) **ELECTRICAL SAFETY DEVICES AND SYSTEMS FOR USE WITH ELECTRICAL WIRING, AND METHODS FOR USING SAME**

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(73) Assignee: **Newire, Inc.**, Knoxville, TN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 646 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/398,660**

(22) Filed: **Mar. 5, 2009**

(65) **Prior Publication Data**

US 2009/0201027 A1 Aug. 13, 2009

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 11/782,450, filed on Jul. 24, 2007, now Pat. No. 7,915,899.

(60) Provisional application No. 61/034,002, filed on Mar. 5, 2008, provisional application No. 60/820,197, filed on Jul. 24, 2006.

(51) **Int. Cl.**
***G01R 31/02*** (2006.01)
***H02H 3/00*** (2006.01)

(52) **U.S. Cl.** .......................................... **324/539**; 361/42

(58) **Field of Classification Search** ........................ None
See application file for complete search history.

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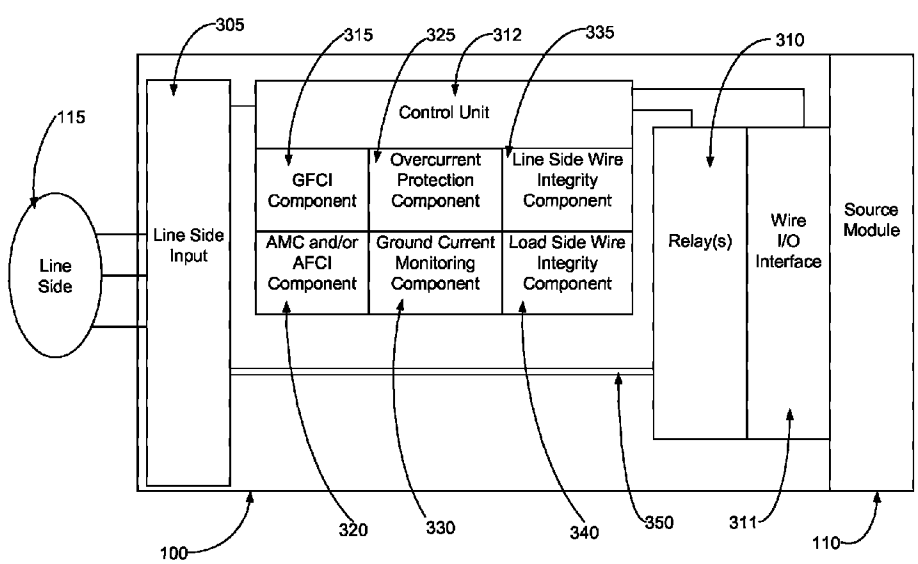
*Primary Examiner* — Jeff Natalini
(74) *Attorney, Agent, or Firm* — Sutherland Asbill & Brennan LLP

(57) **ABSTRACT**

Disclosed are systems and methods for monitoring an electrical wire. An appropriate safety device is utilized to monitor the electrical wire. The safety device includes a line side input configured to connect a line side power source and receive an electrical power signal from the line side power source. Additionally, the safety device includes a wire connection configured to connect to an electrical wire. The safety device further includes at least one relay or other suitable disconnection component configured to control the communication of the electrical power signal onto the electrical wire. The safety device also includes a control unit configured to test the electrical wire for at least one of miswires, wire faults, or abnormal conditions and, based at least in part on the results of the testing, to control the actuation of the at least one relay.

**19 Claims, 27 Drawing Sheets**



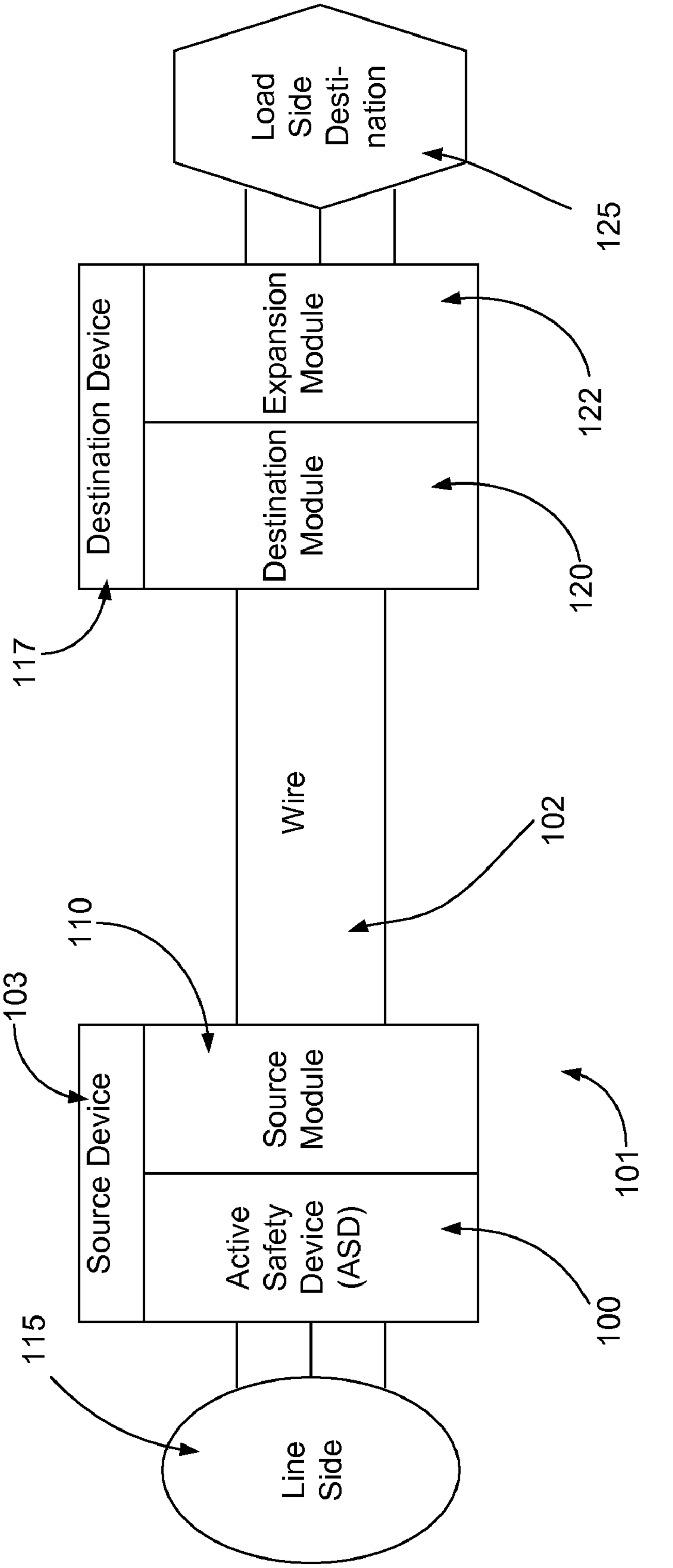

Load Side Desti- nation
125
Destination Device
Expansion Module
122
Destination Module
120
117
Wire
102
110
103
Source Device
Source Module
101
Active Safety Device (ASD)
100
115
Line Side

FIG. 1

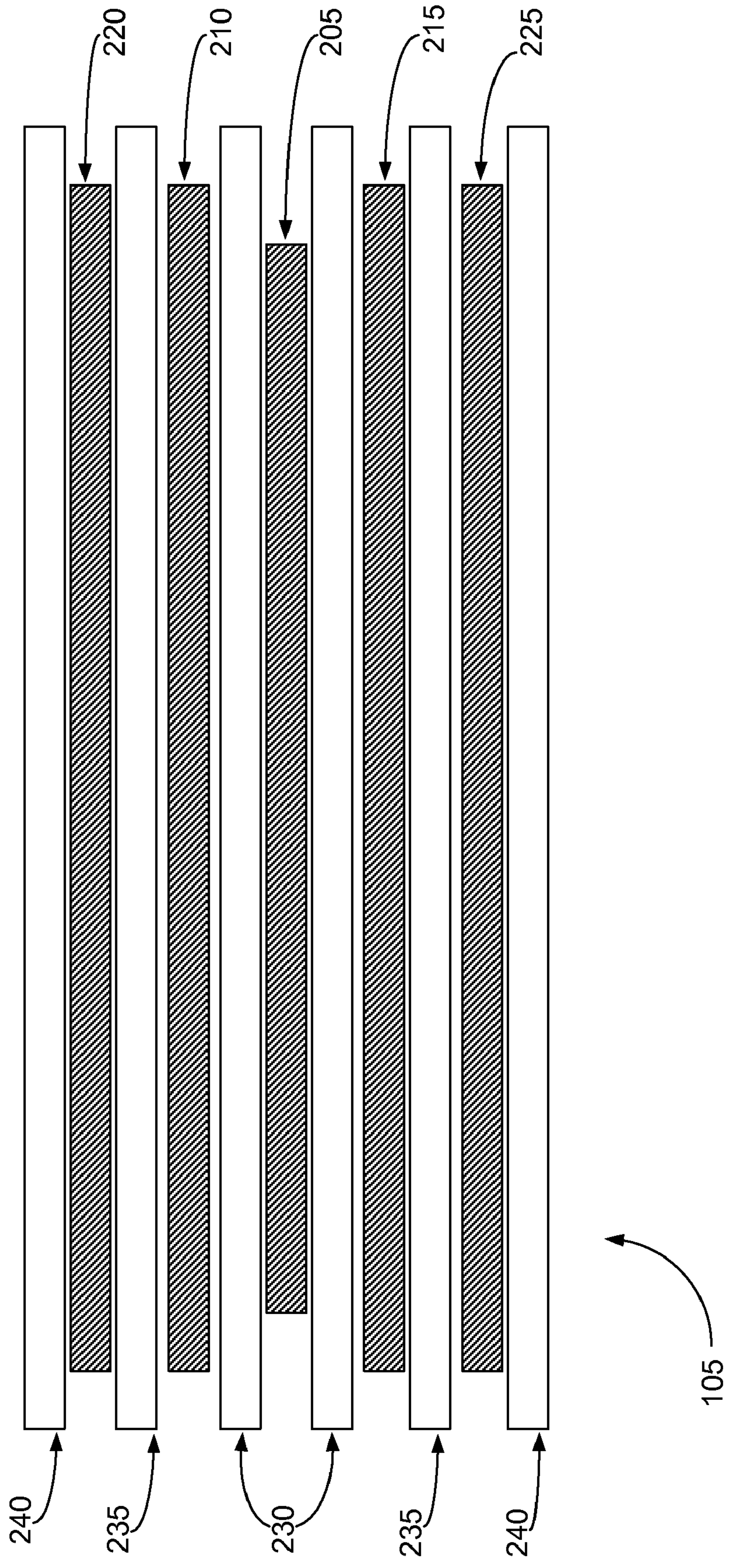



FIG. 2A

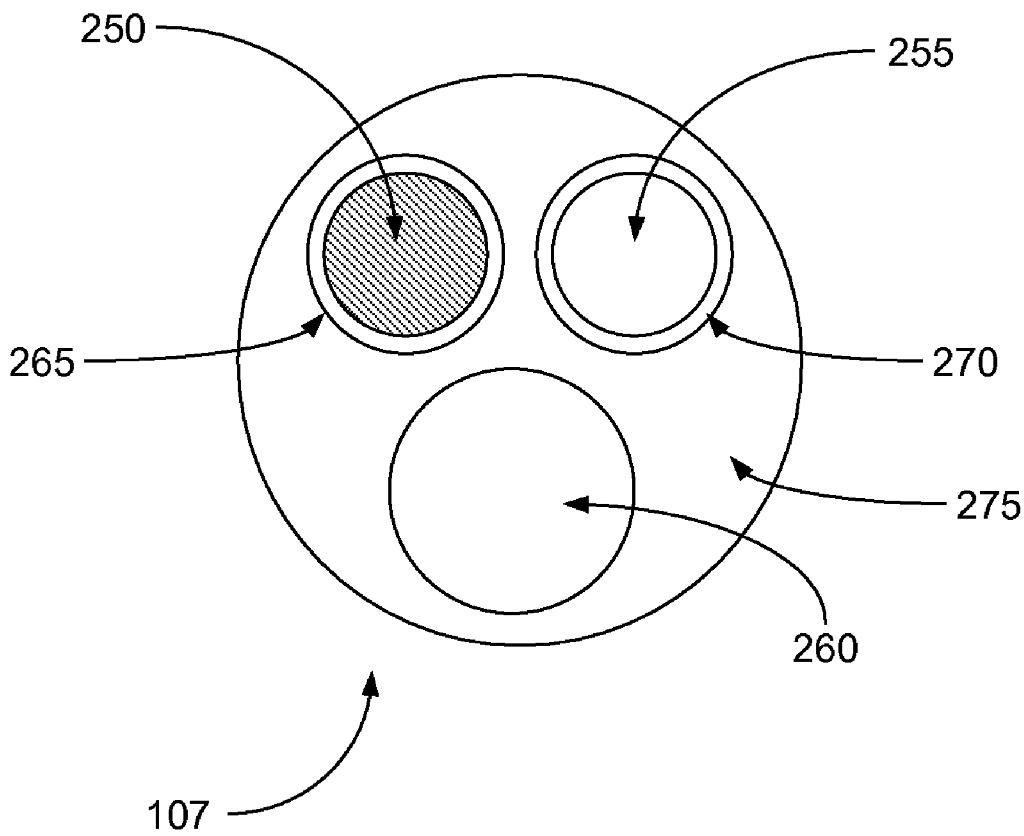



FIG. 2B

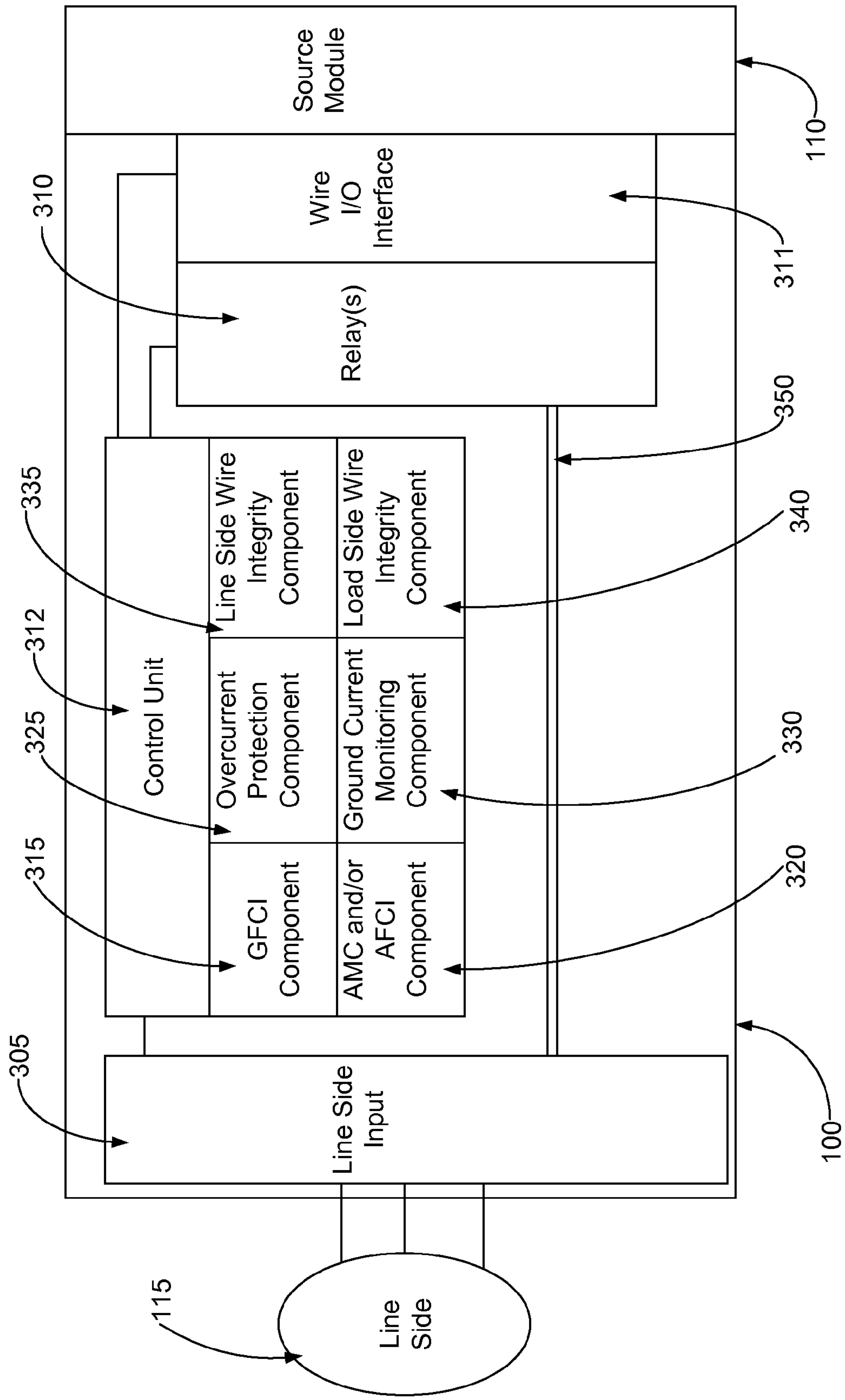

Source Module
110
Wire I/O Interface
311
310
Relay(s)
350
Control Unit
312
Line Side Wire Integrity Component
335
Load Side Wire Integrity Component
340
Overcurrent Protection Component
325
Ground Current Monitoring Component
330
GFCI Component
315
AMC and/or AFCI Component
320
Line Side Input
305
100
Line Side
115

FIG. 3

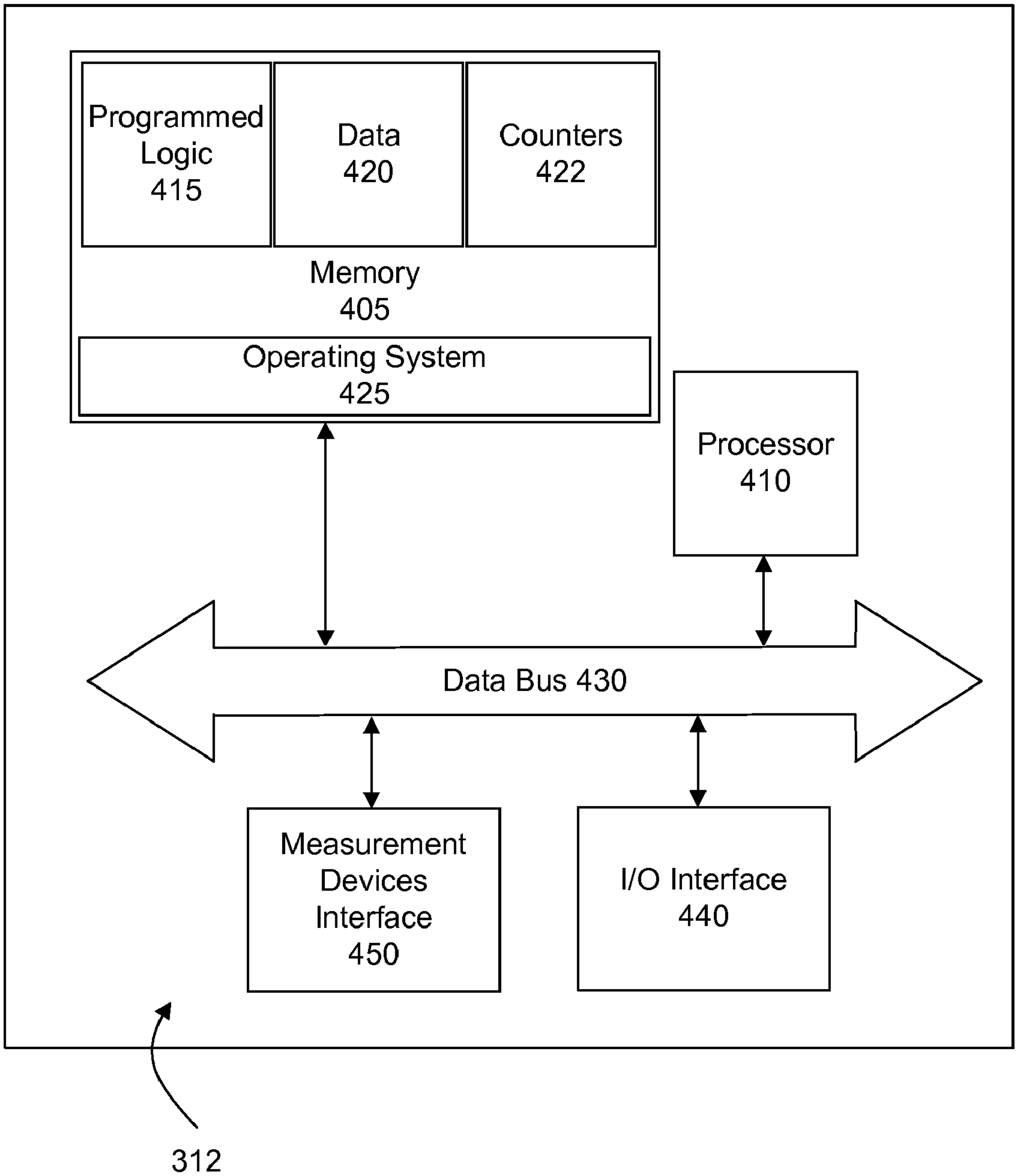

Programmed Logic 415
Data 420
Counters 422
Memory 405
Operating System 425
Processor 410
Data Bus 430
Measurement Devices Interface 450
I/O Interface 440
312

FIG. 4A

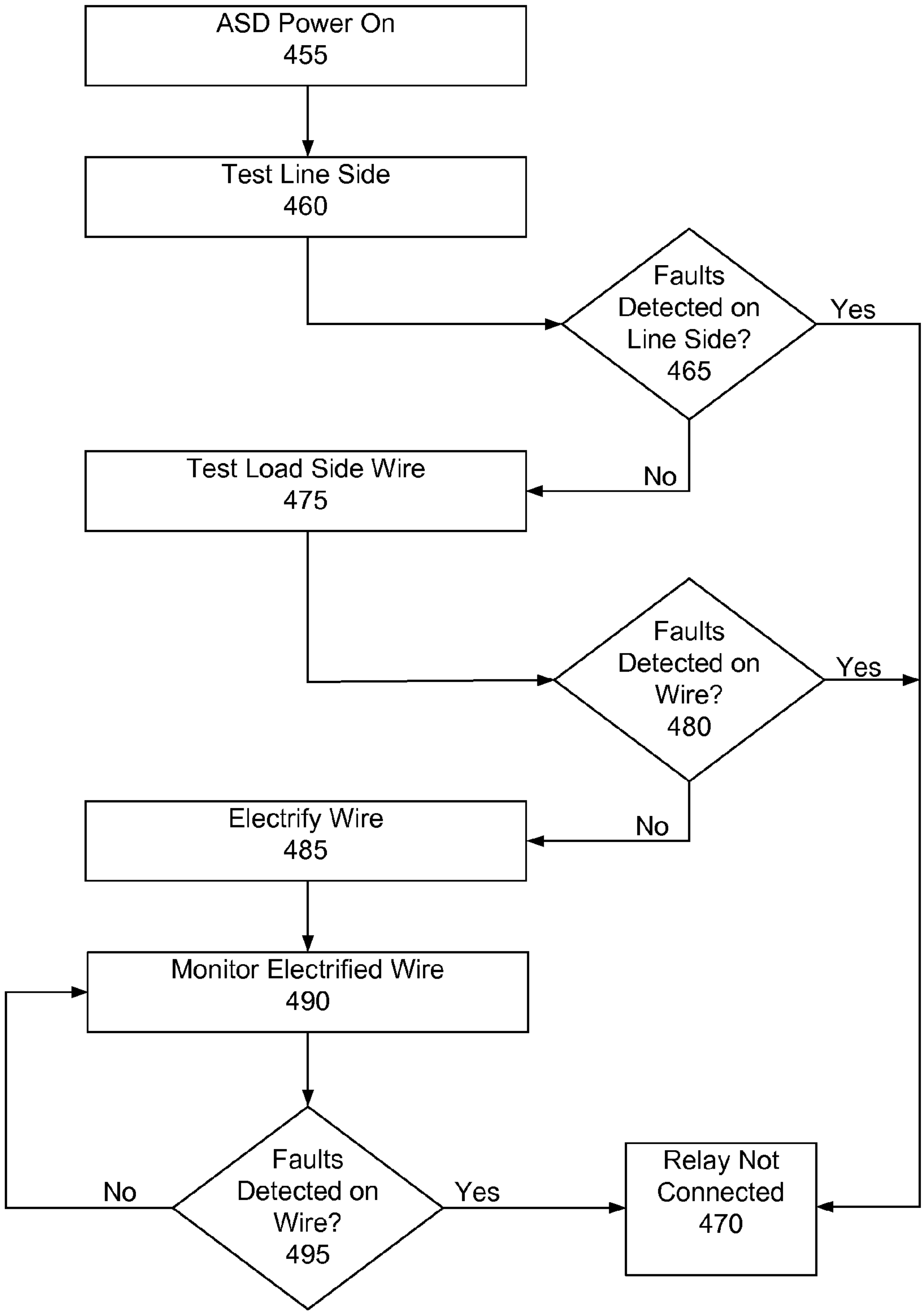

ASD Power On
455
Test Line Side
460
Faults Detected on Line Side?
465
Yes
No
Test Load Side Wire
475
Faults Detected on Wire?
480
Yes
No
Electrify Wire
485
Monitor Electrified Wire
490
Faults Detected on Wire?
495
No
Yes
Relay Not Connected
470

FIG. 4B

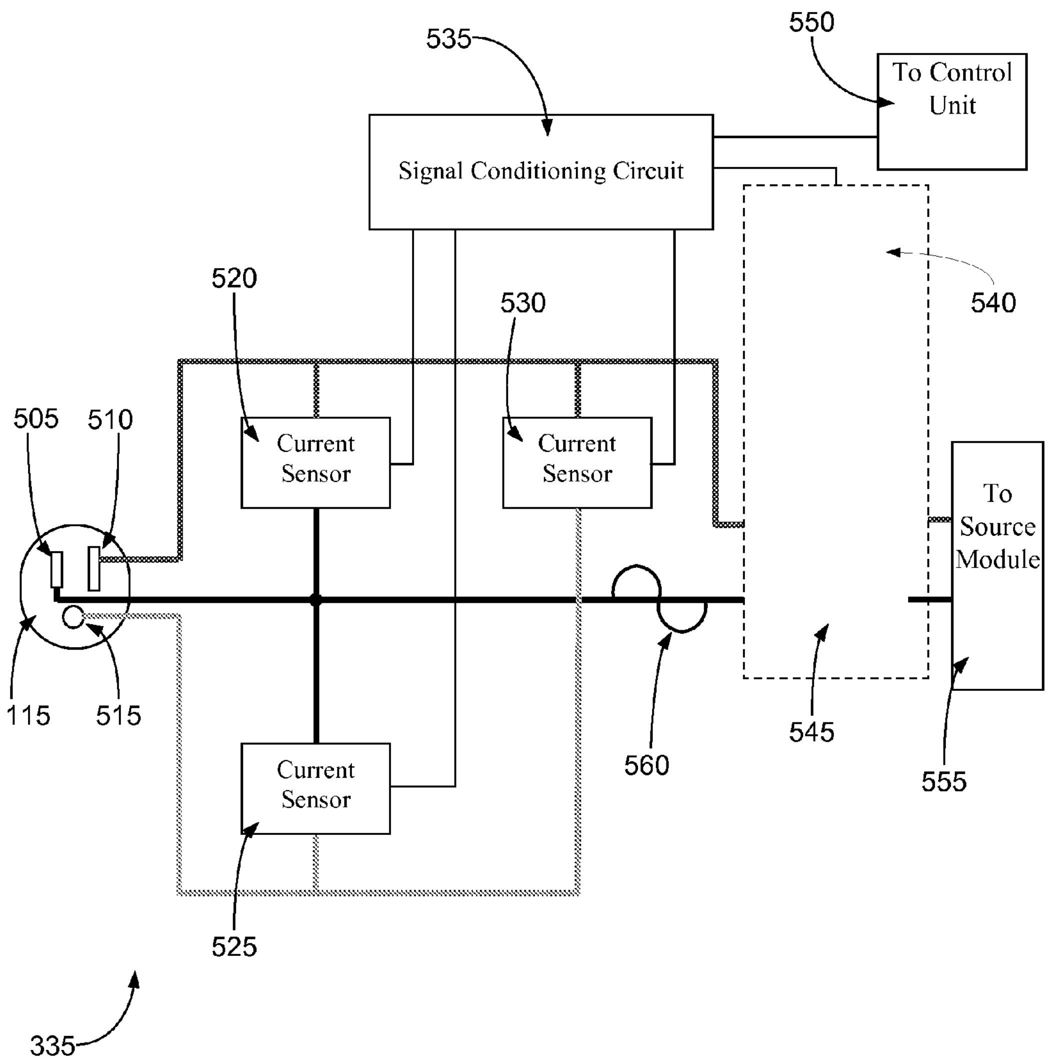
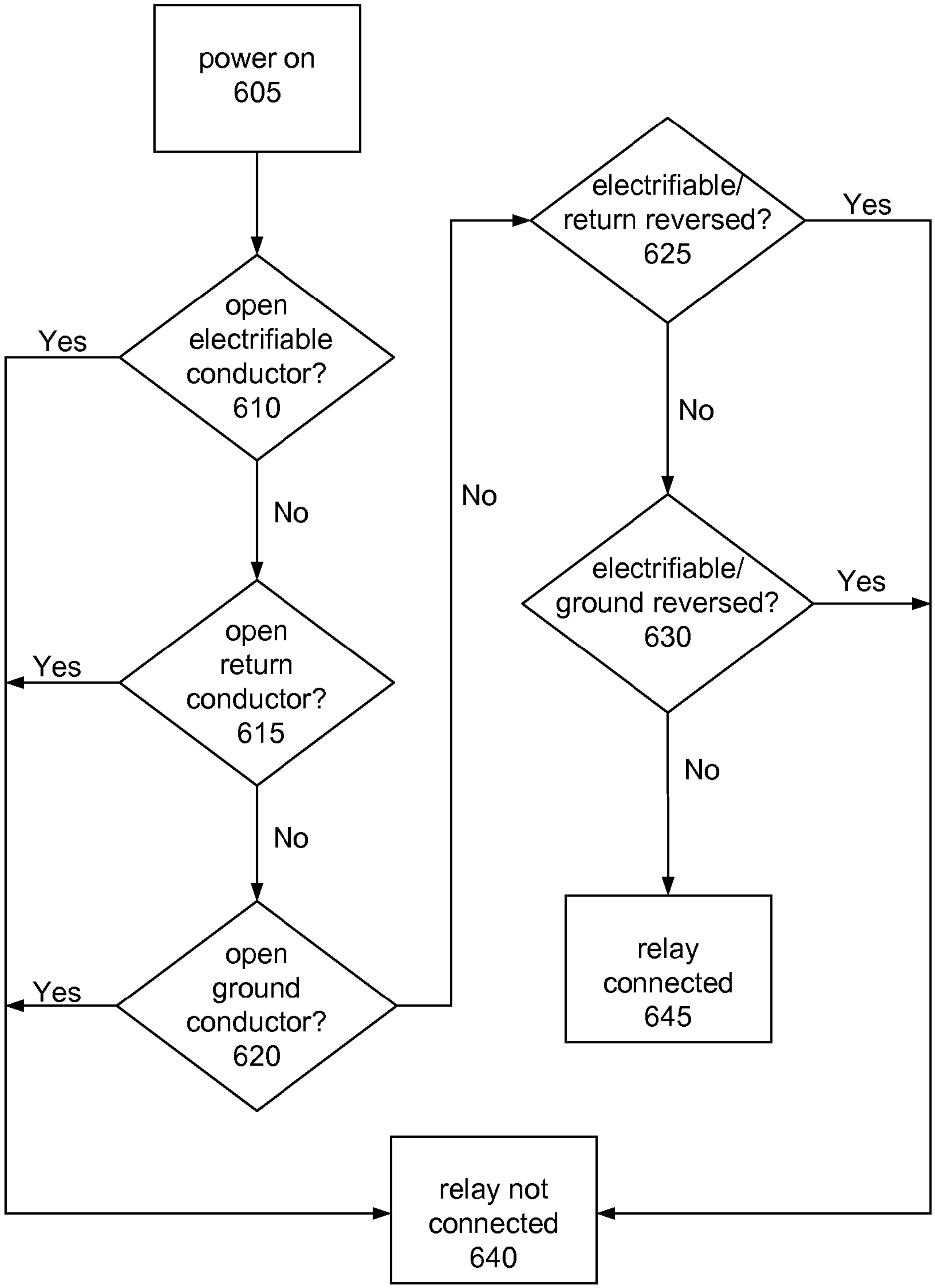
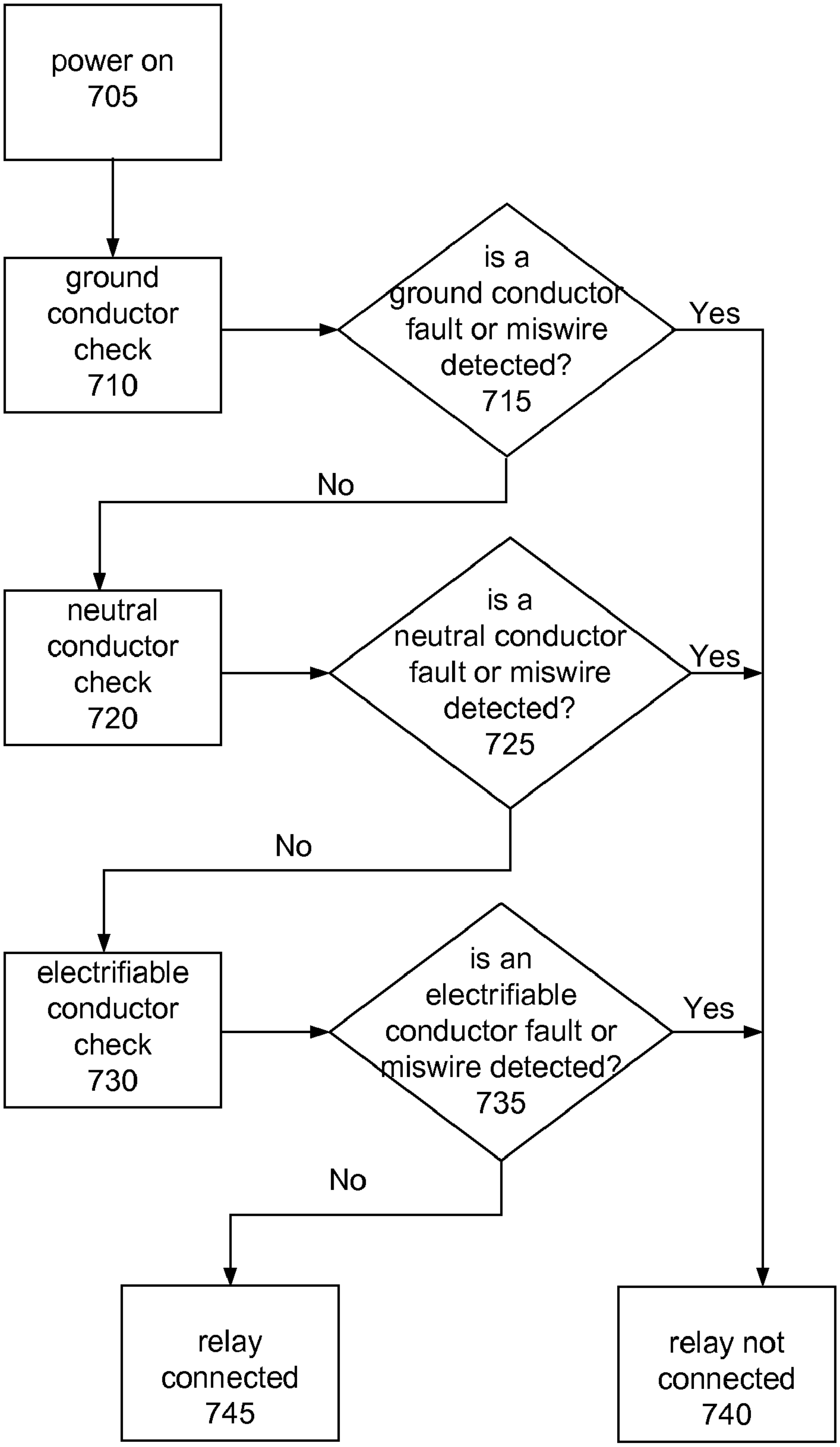

535
550
To Control Unit
Signal Conditioning Circuit
520
530
540
505
510
Current Sensor
Current Sensor
To Source Module
115
515
545
560
555
Current Sensor
525
335

FIG. 5



power on
605
open
electrifiable
conductor?
610
Yes
No
open
return
conductor?
615
Yes
No
open
ground
conductor?
620
Yes
No
electrifiable/
return reversed?
625
Yes
No
electrifiable/
ground reversed?
630
Yes
No
relay
connected
645
relay not
connected
640


FIG. 6



power on
705
ground conductor check
710
is a ground conductor fault or miswire detected?
715
Yes
No
neutral conductor check
720
is a neutral conductor fault or miswire detected?
725
Yes
No
electrifiable conductor check
730
is an electrifiable conductor fault or miswire detected?
735
Yes
No
relay connected
745
relay not connected
740


FIG. 7

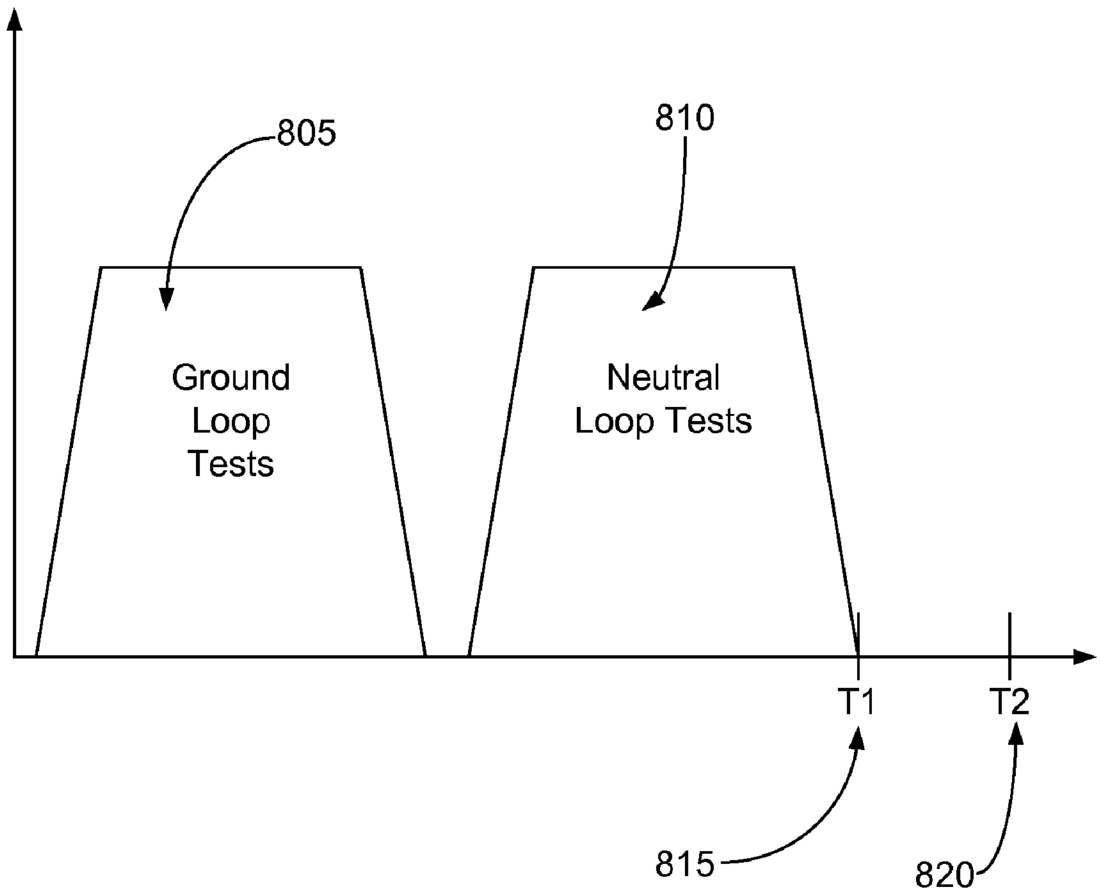



FIG. 8A

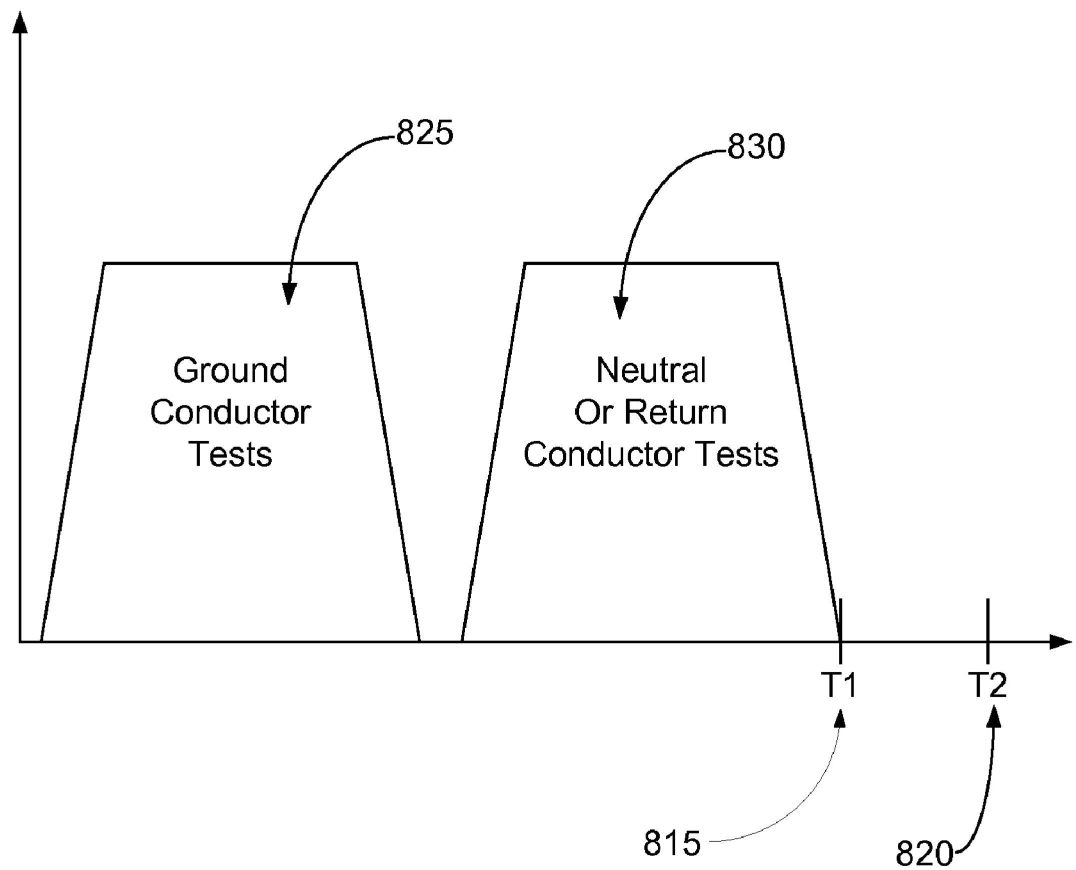

825
830
Ground
Conductor
Tests
Neutral
Or Return
Conductor Tests
T1
T2
815
820

FIG. 8B

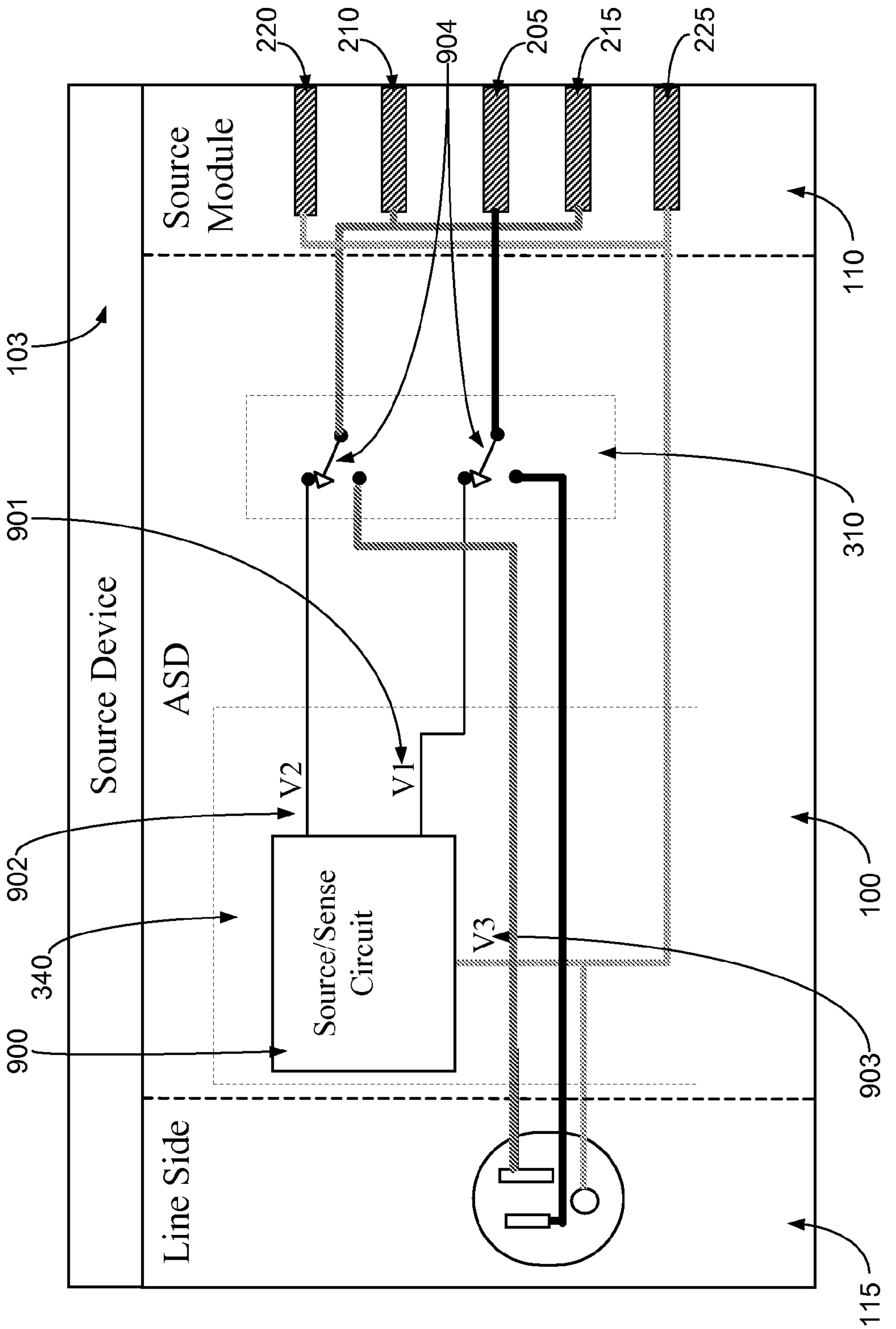

220
210
904
205
215
225
Source Module
103
110
Source Device
ASD
901
310
V2
V1
902
Source/Sense Circuit
340
V3
100
900
903
Line Side
115

FIG. 9A

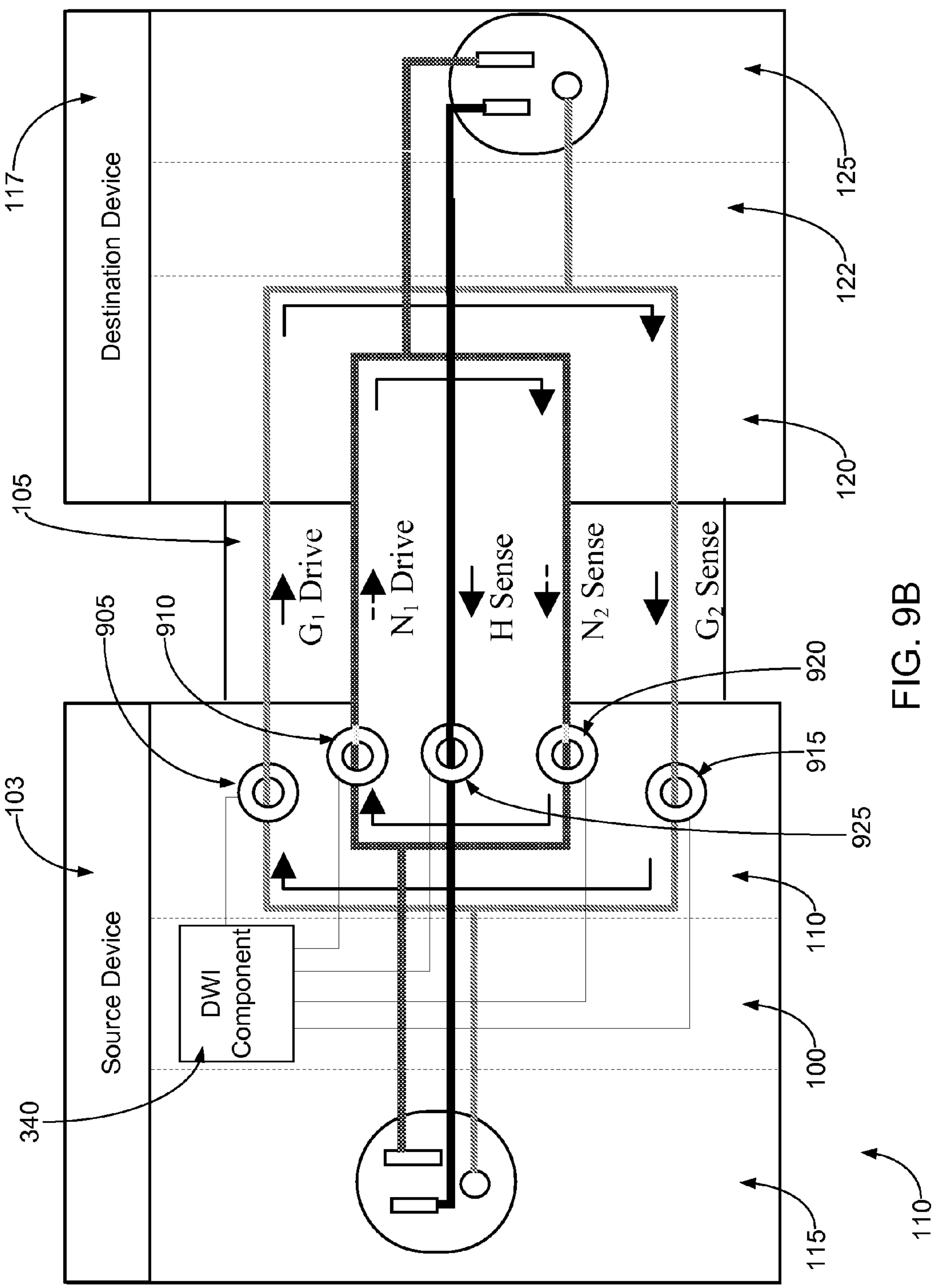

117
Destination Device
125
122
120
105
$G_1$ Drive
$N_1$ Drive
H Sense
$N_2$ Sense
$G_2$ Sense
905
910
920
915
925
103
Source Device
DWI Component
340
110
100
115
110

FIG. 9B

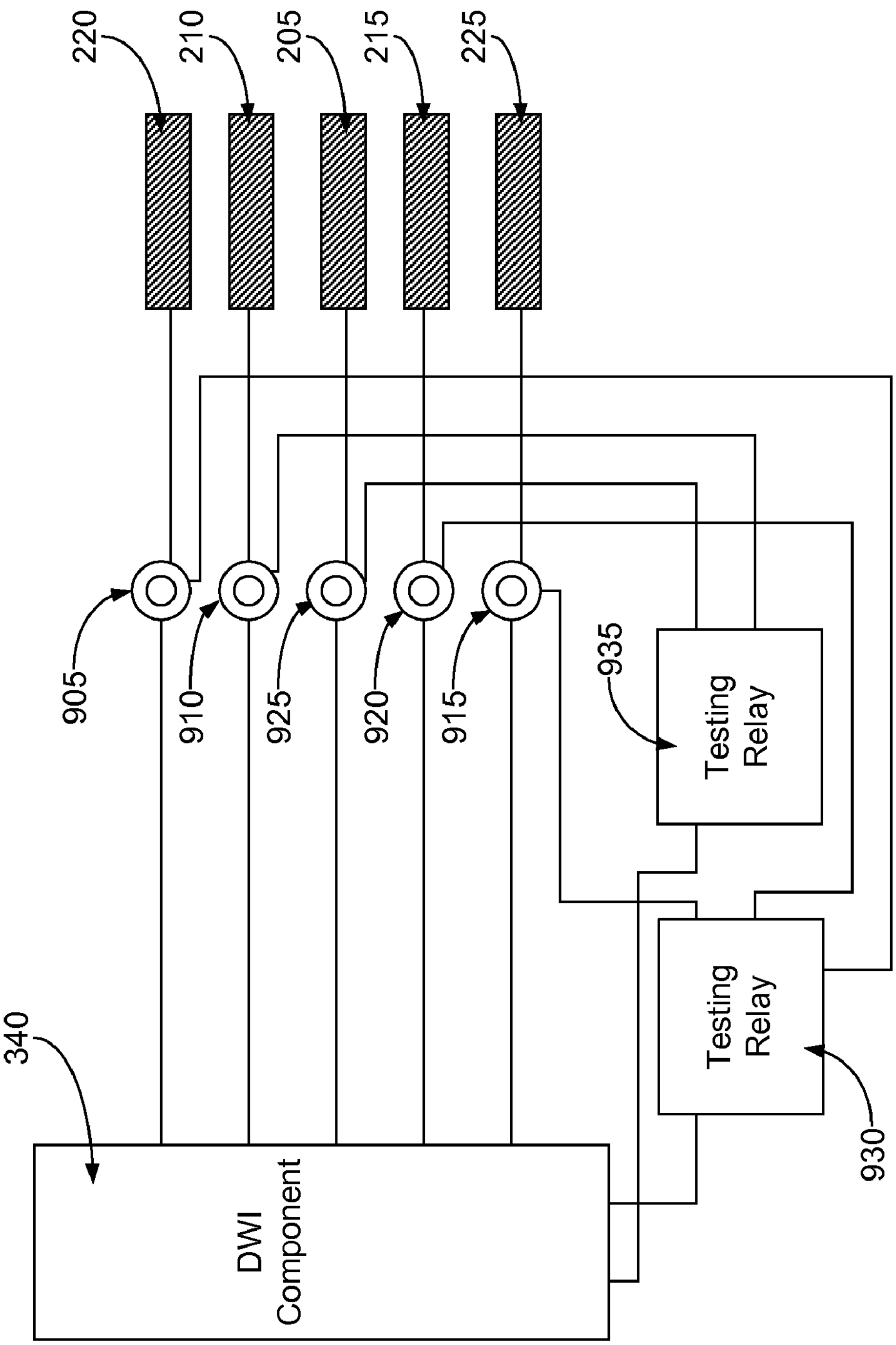

220
210
205
215
225
905
910
925
920
915
935
Testing Relay
Testing Relay
930
340
DWI Component

FIG. 9C

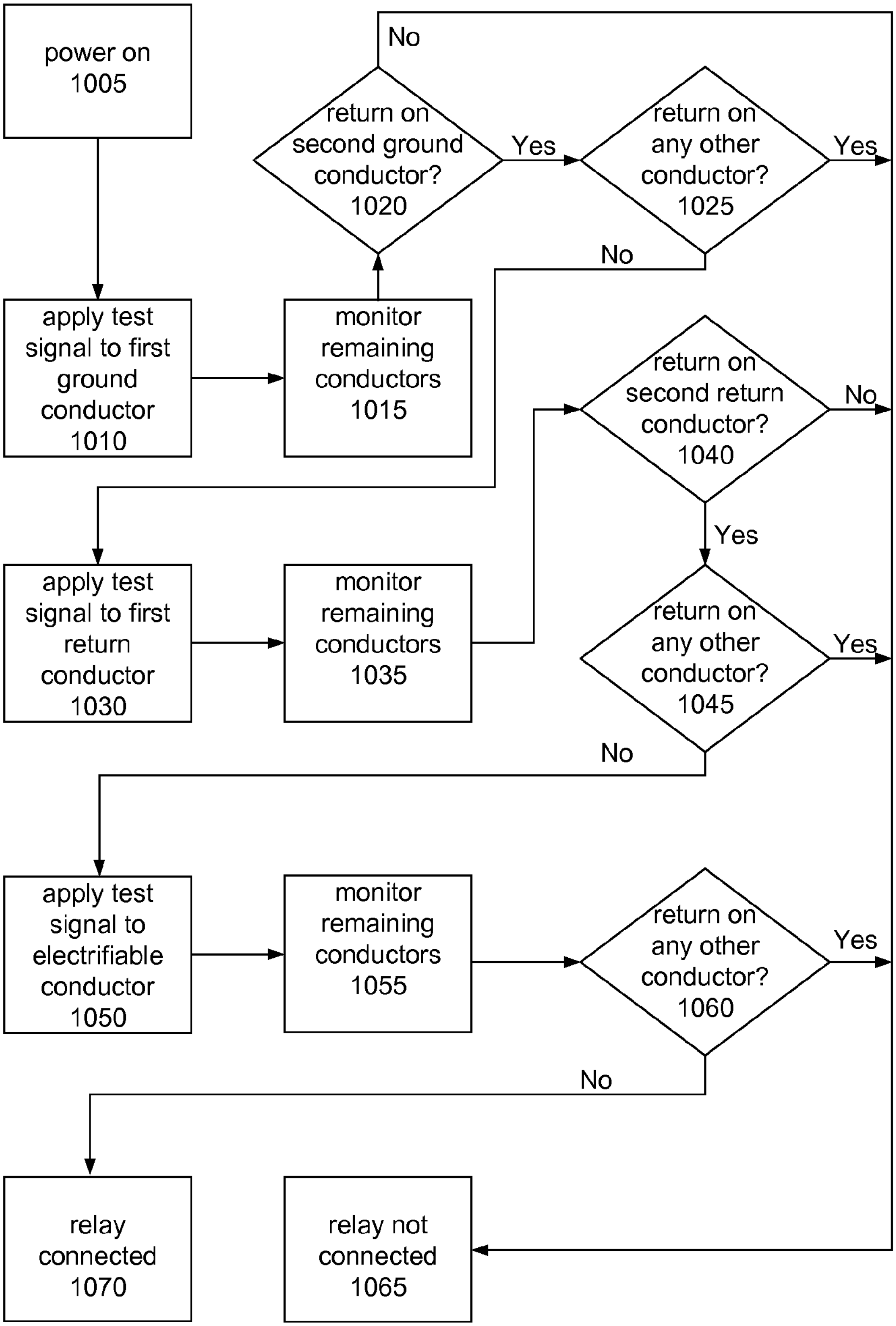

power on 1005
apply test signal to first ground conductor 1010
monitor remaining conductors 1015
return on second ground conductor? 1020
No
Yes
return on any other conductor? 1025
Yes
No
apply test signal to first return conductor 1030
monitor remaining conductors 1035
return on second return conductor? 1040
No
Yes
return on any other conductor? 1045
Yes
No
apply test signal to electrifiable conductor 1050
monitor remaining conductors 1055
return on any other conductor? 1060
Yes
No
relay connected 1070
relay not connected 1065

FIG. 10

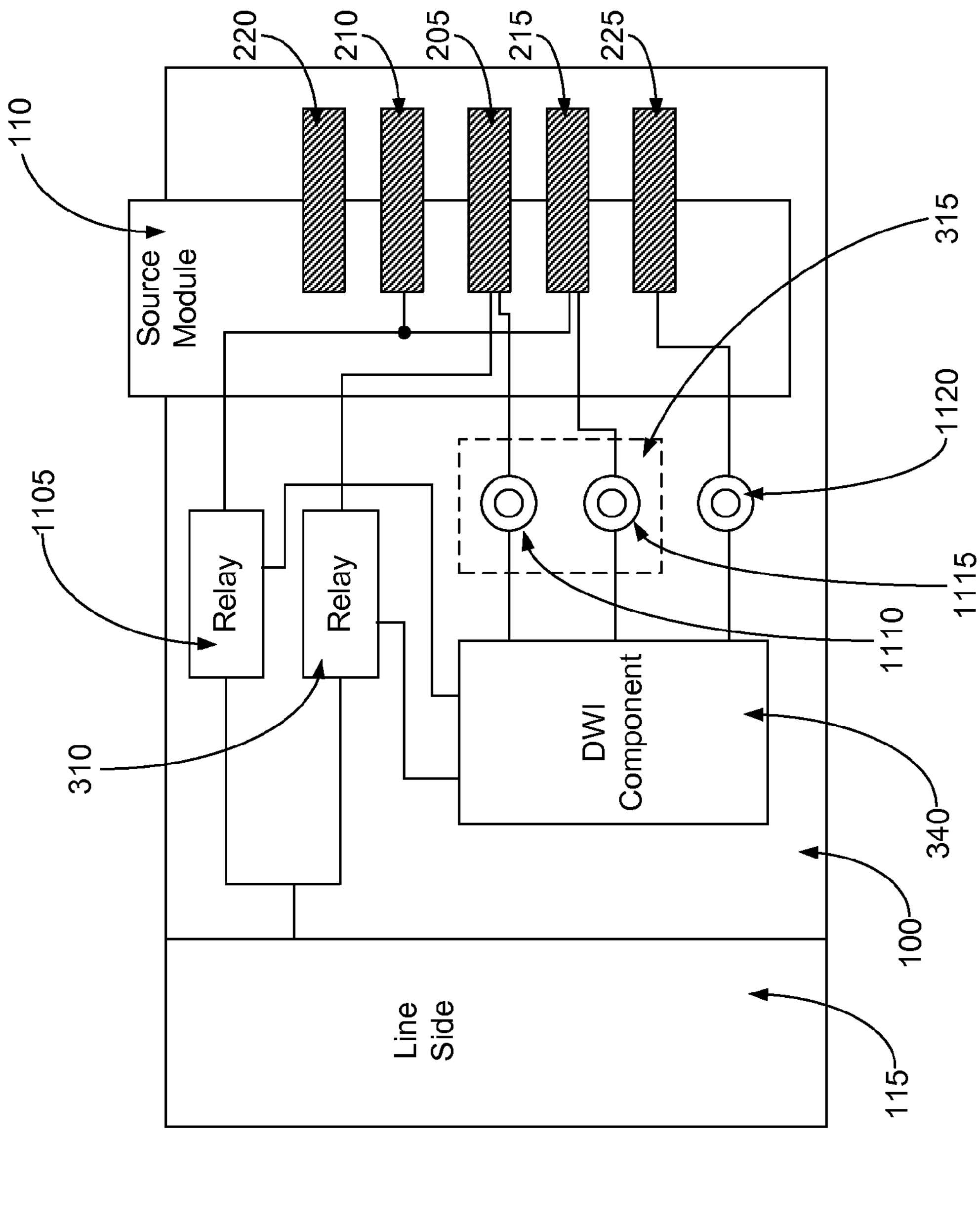

110
220
210
205
215
225
Source Module
315
1120
1105
Relay
Relay
1110
1115
310
DWI Component
340
100
Line Side
115

FIG. 11

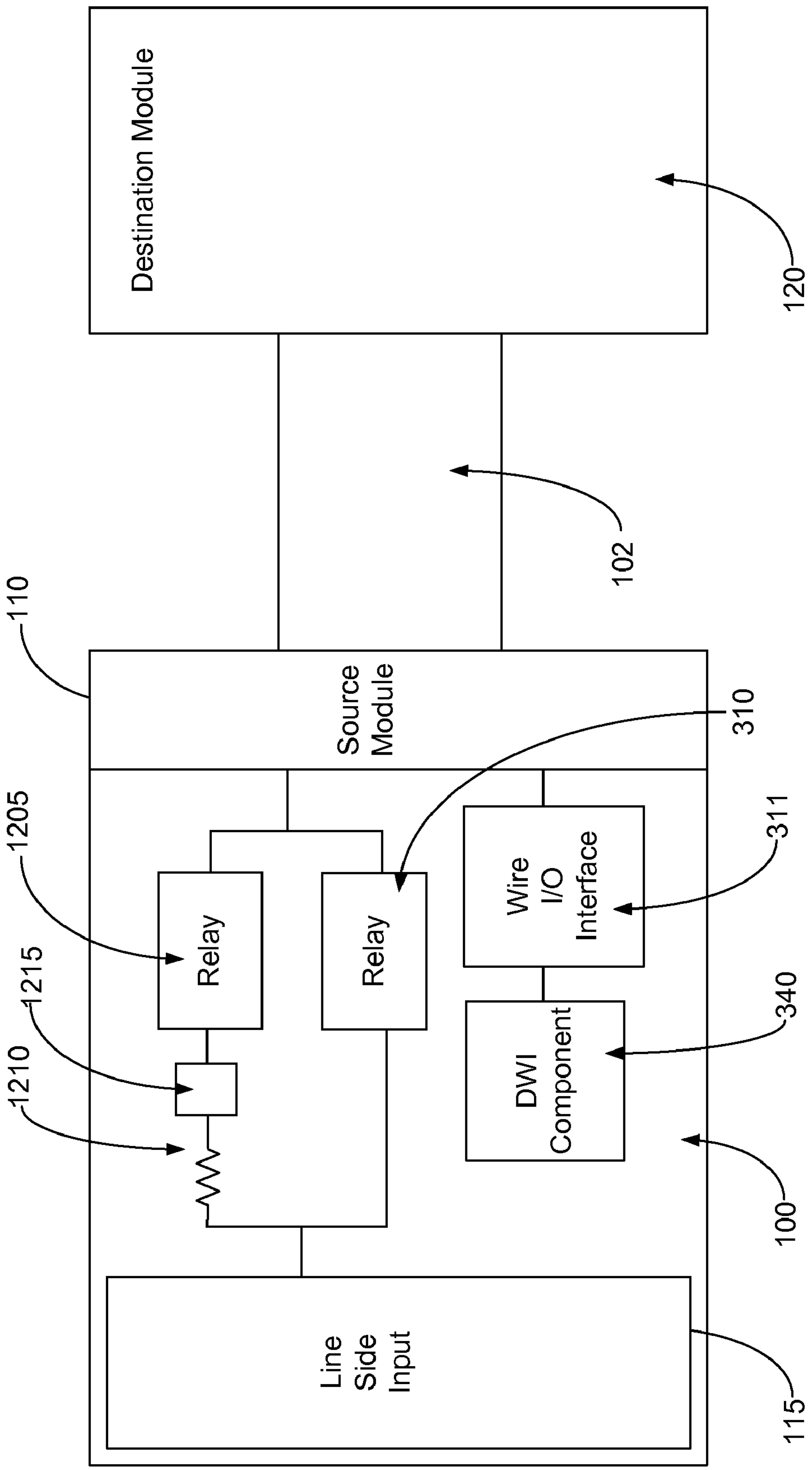

Destination Module
120
102
110
Source Module
310
1205
Relay
Relay
1215
1210
Wire I/O Interface
311
DWI Component
340
100
Line Side Input
115

FIG. 12

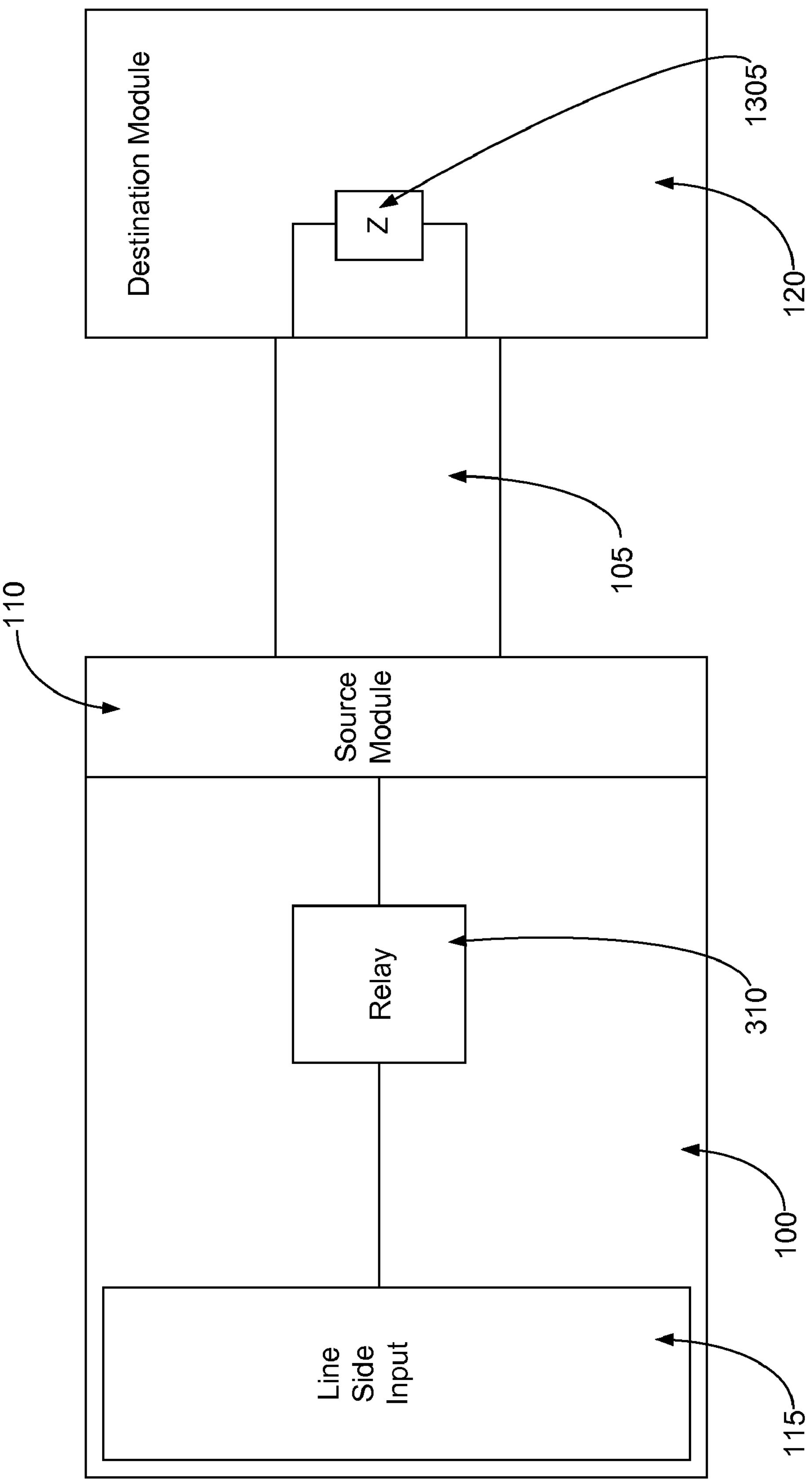

Destination Module
Z
1305
120
105
110
Source Module
Relay
310
100
Line Side Input
115

FIG. 13

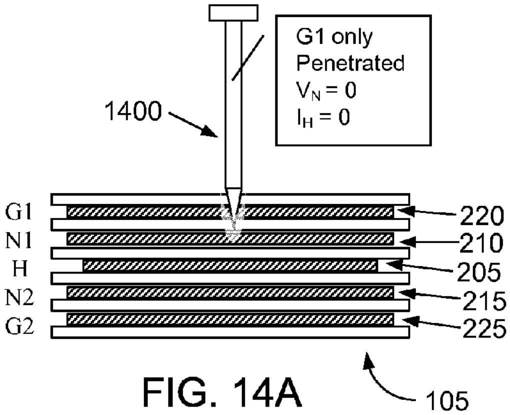



FIG. 14A

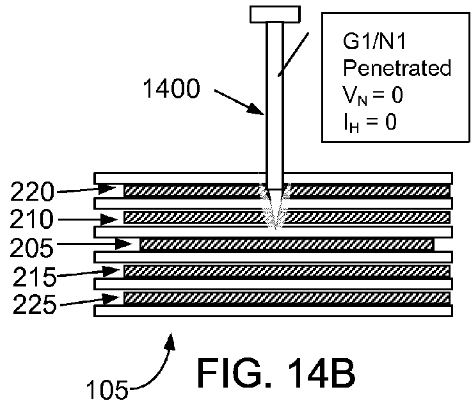



FIG. 14B

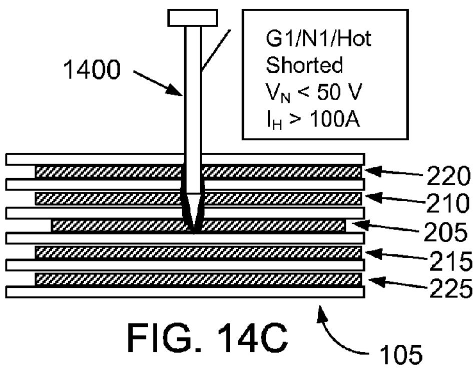



FIG. 14C

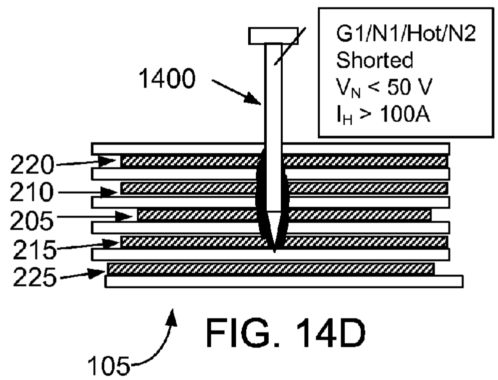



FIG. 14D

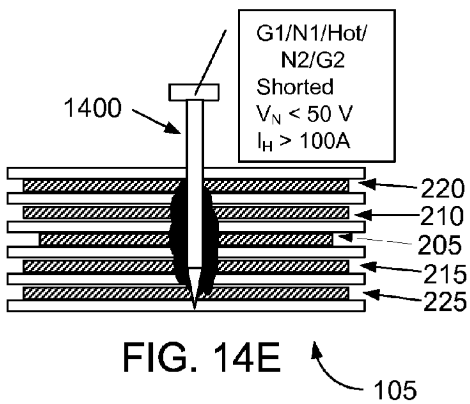



FIG. 14E

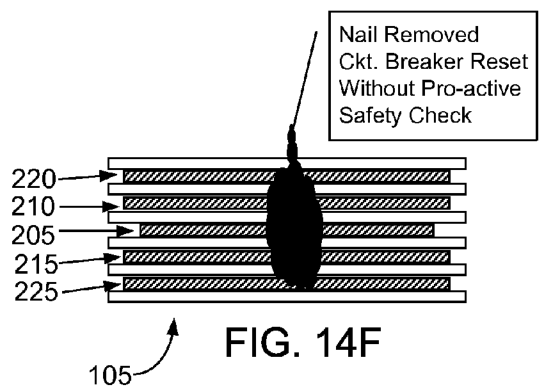



FIG. 14F

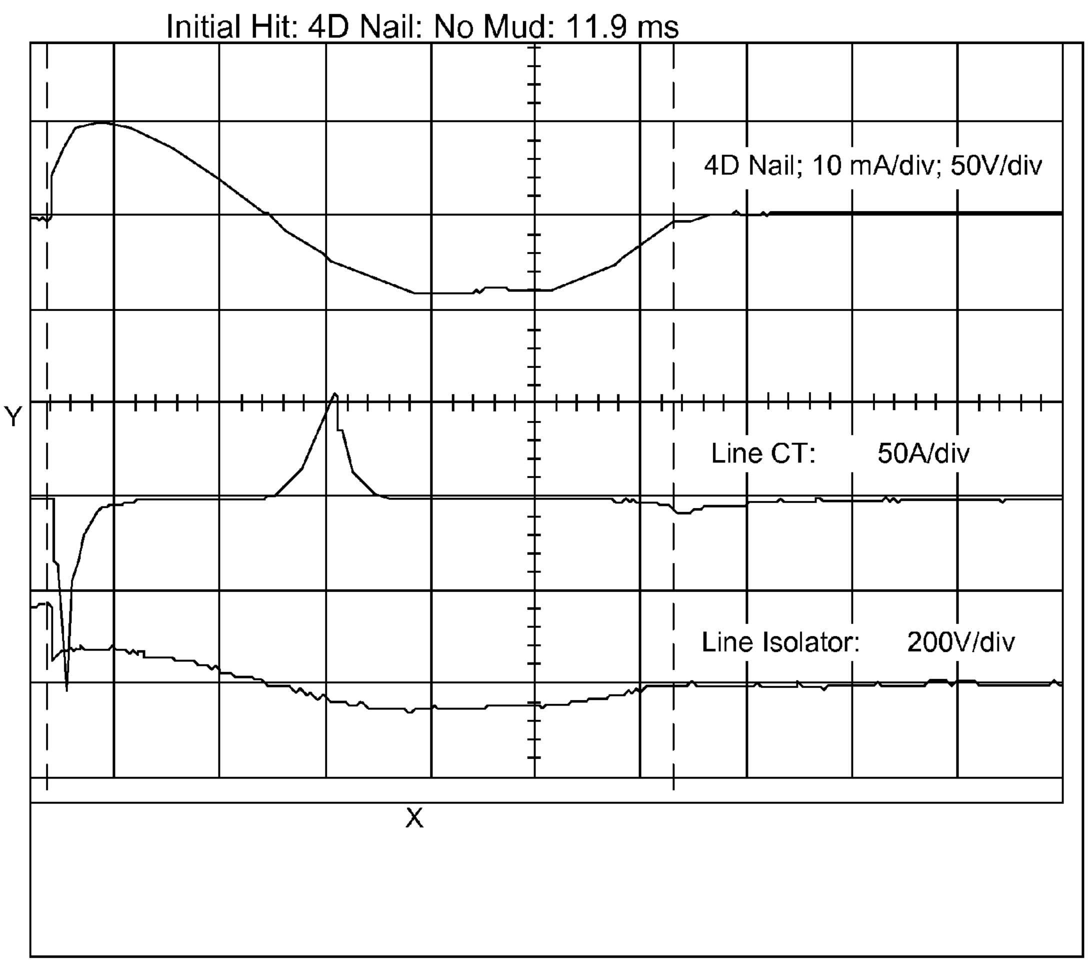

Initial Hit: 4D Nail: No Mud: 11.9 ms
4D Nail; 10 mA/div; 50V/div
Y
Line CT: 50A/div
Line Isolator: 200V/div
X

FIG. 15

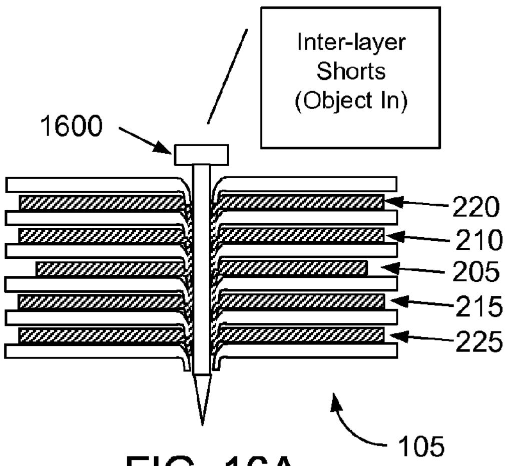



FIG. 16A

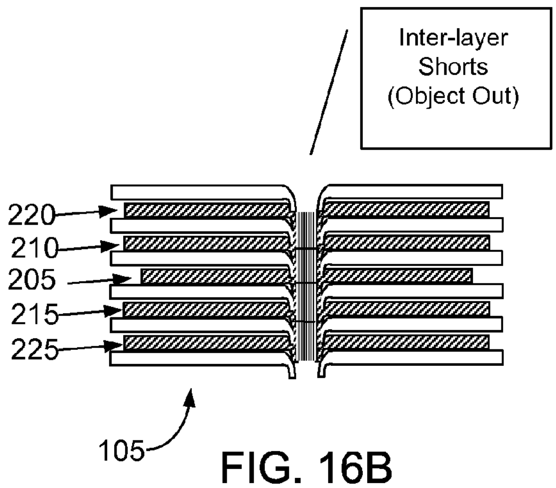



FIG. 16B

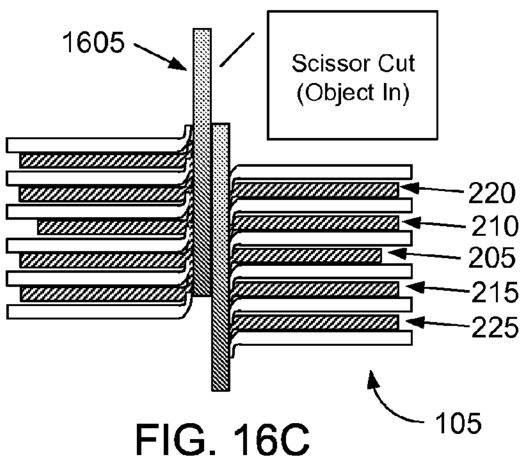



FIG. 16C

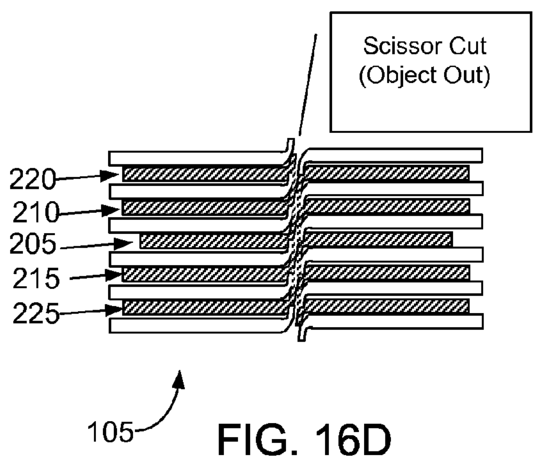



FIG. 16D

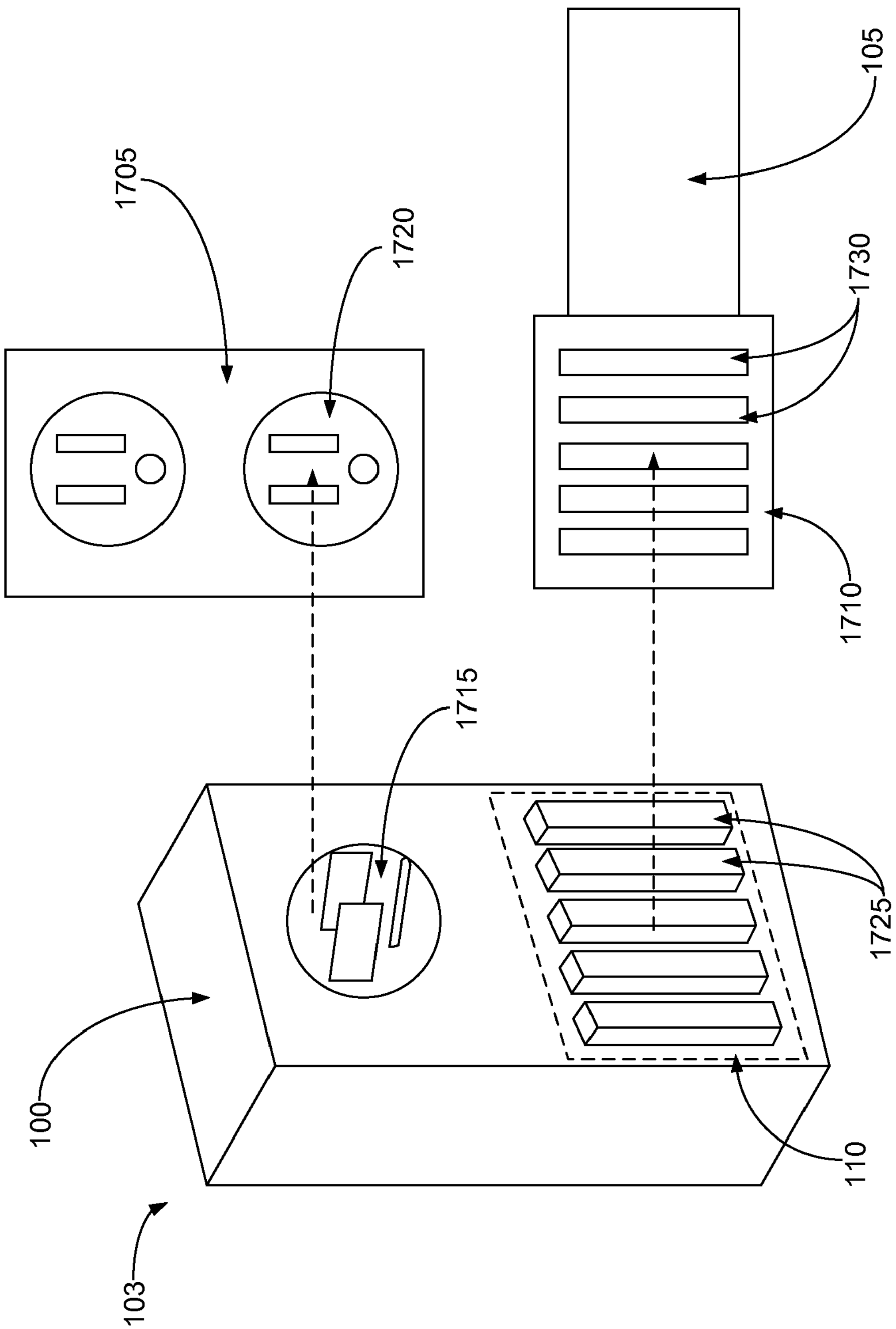



FIG. 17A

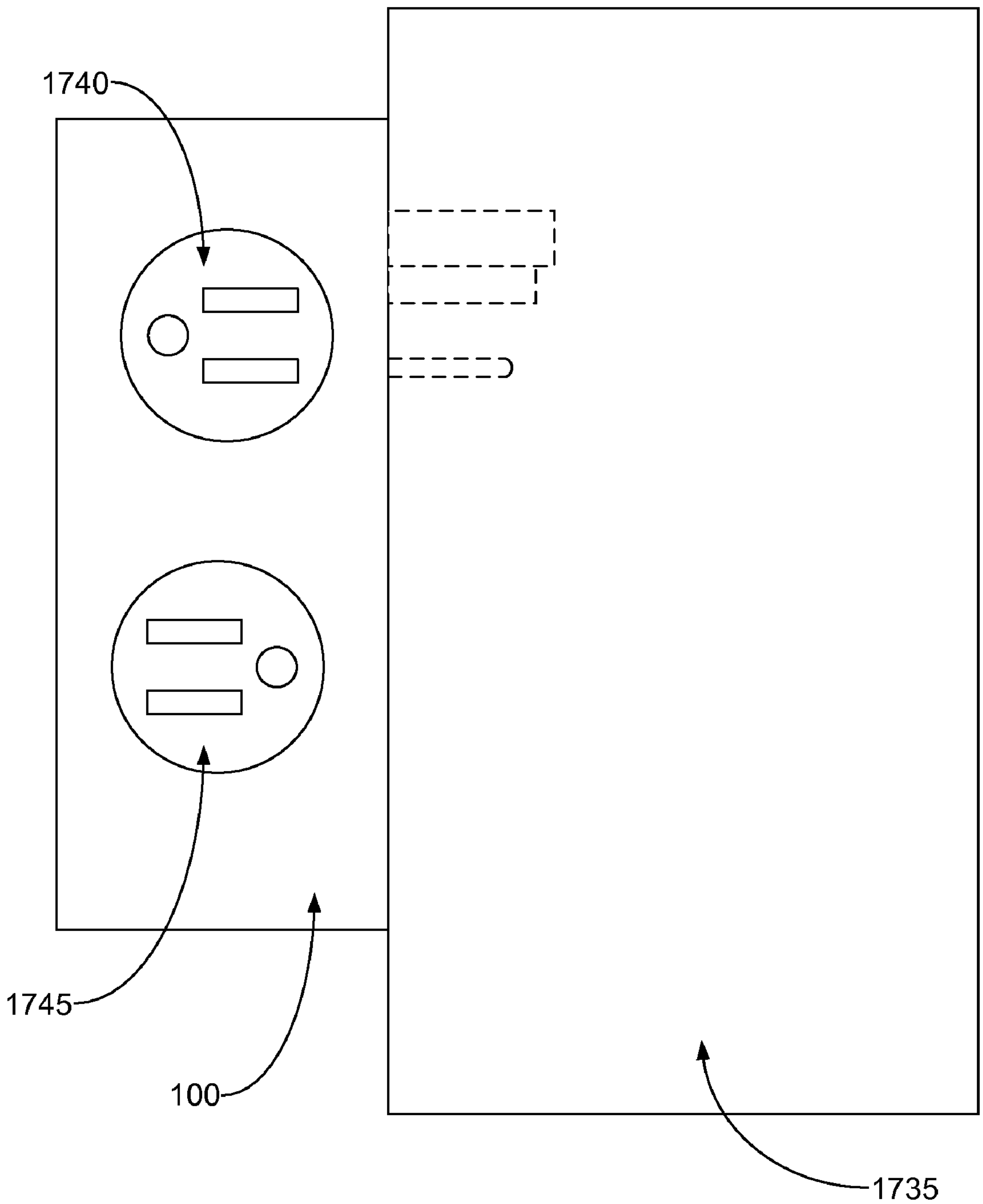



FIG. 17B

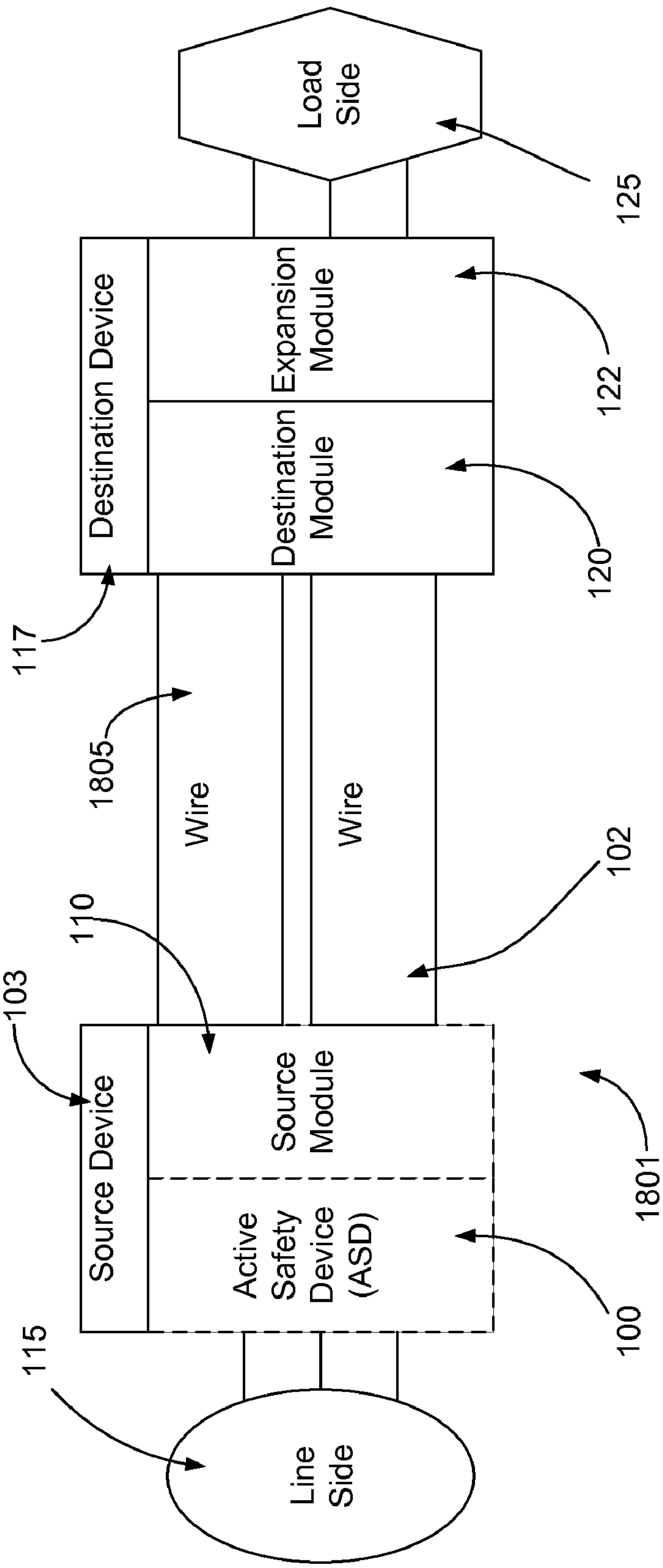
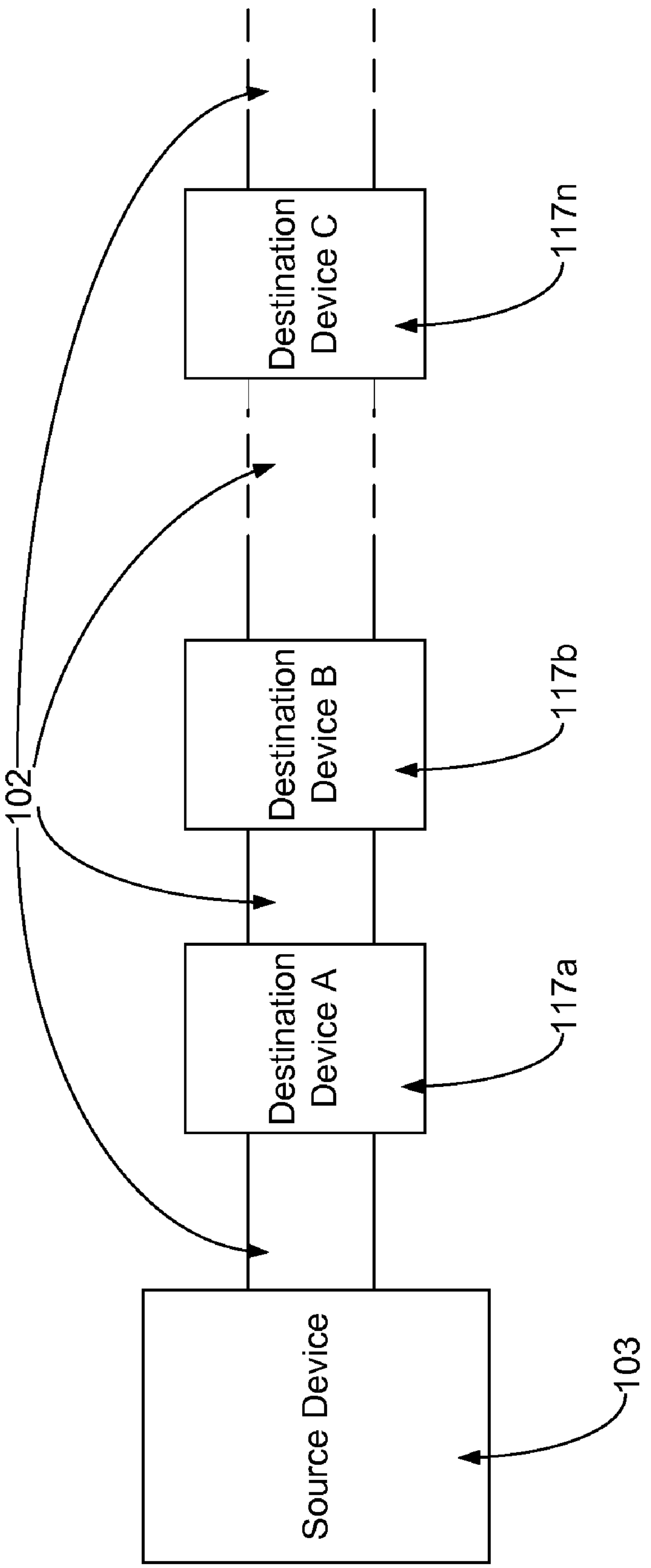

Load Side
125
Destination Device
Expansion Module
122
Destination Module
120
117
Wire
Wire
1805
102
Source Device
103
110
Source Module
Active Safety Device (ASD)
100
1801
Line Side
115

FIG. 18



102
Destination Device C
117n
Destination Device B
117b
Destination Device A
117a
Source Device
103


FIG. 19

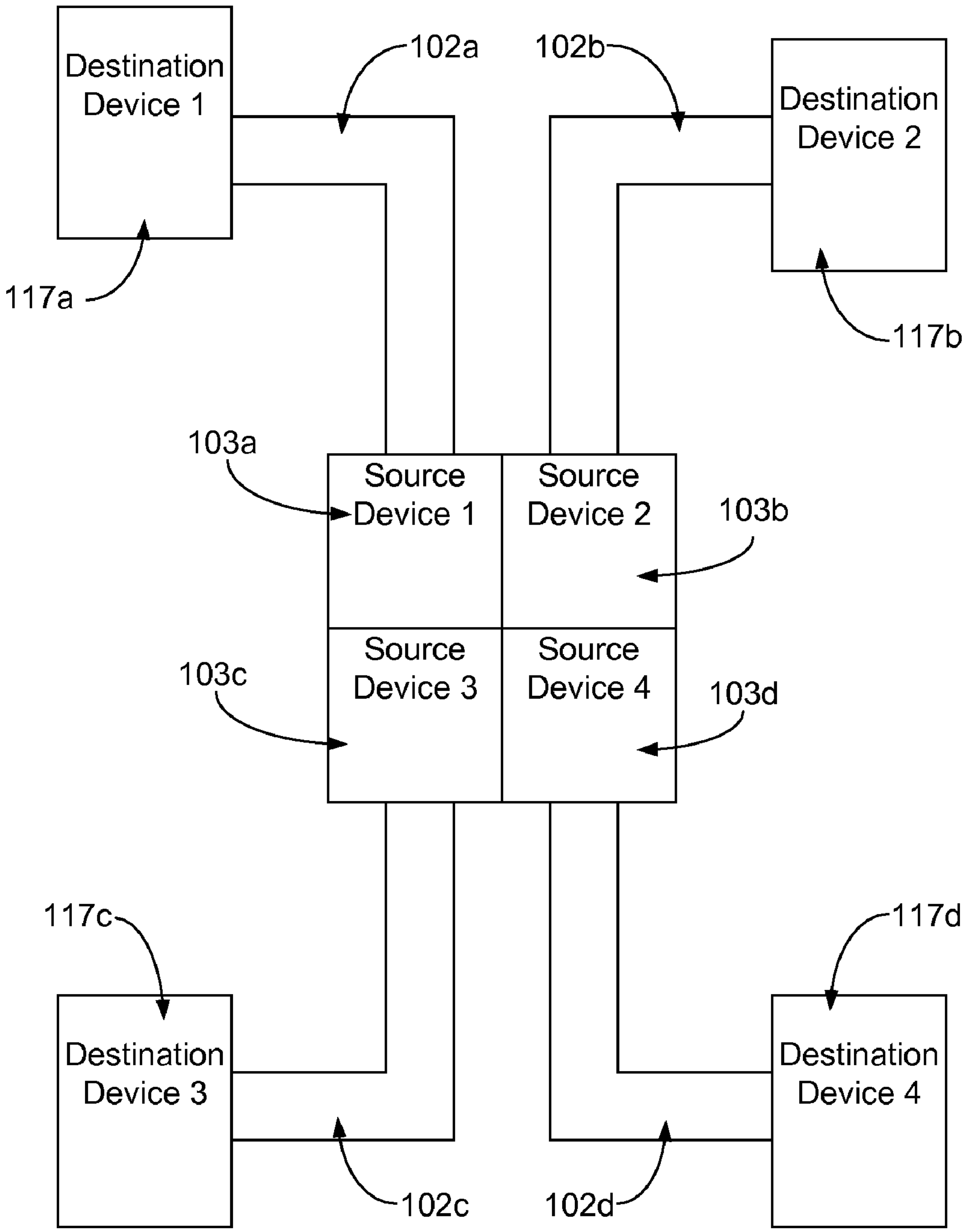

Destination Device 1
102a
102b
Destination Device 2
117a
117b
103a
Source Device 1
Source Device 2
103b
Source Device 3
Source Device 4
103c
103d
117c
117d
Destination Device 3
Destination Device 4
102c
102d

FIG. 20

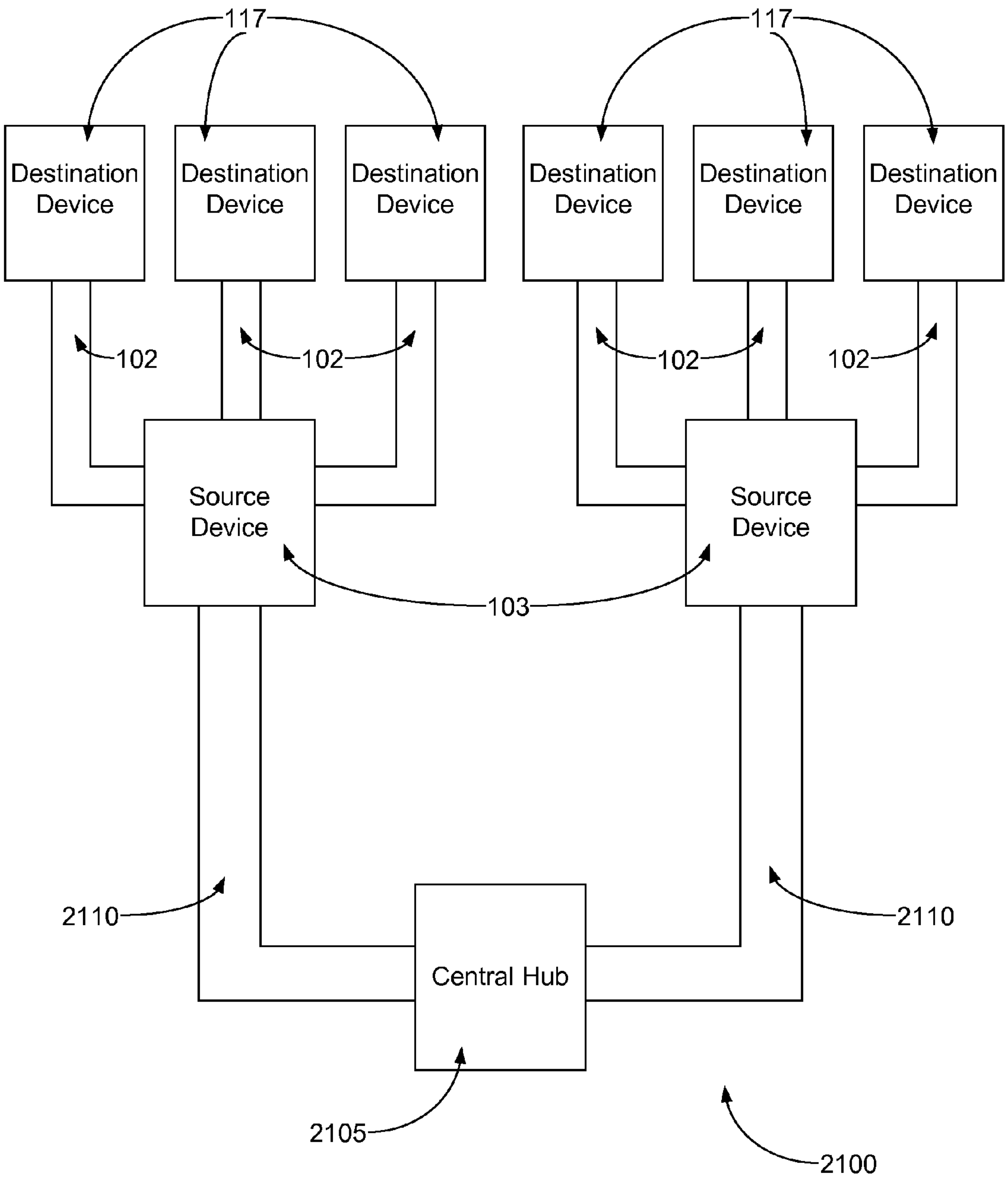

117
117
Destination Device
Destination Device
Destination Device
Destination Device
Destination Device
Destination Device
102
102
102
102
Source Device
Source Device
103
2110
2110
Central Hub
2105
2100

FIG. 21

# ELECTRICAL SAFETY DEVICES AND SYSTEMS FOR USE WITH ELECTRICAL WIRING, AND METHODS FOR USING SAME

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in part of co-pending U.S. patent application Ser. No. 11/782,450, filed Jul. 24, 2007, entitled ELECTRICAL SAFETY DEVICES AND SYSTEMS FOR USE WITH ELECTRICAL WIRING, AND METHODS FOR USING SAME, which claims priority to U.S. Provisional Application No. 60/820,197, entitled ACTIVE SAFETY DEVICES, which was filed on Jul. 24, 2006. Additionally, the present application claims priority to U.S. Provisional Application No. 61/034,002, filed Mar. 5, 2008, entitled ACTIVE SAFETY DEVICES AND METHODS FOR USE WITH ELECTRICAL WIRE. The disclosures for each of these applications are incorporated herein by reference in their entirety.

## FIELD OF THE INVENTION

Embodiments of the invention generally relate to safety devices and systems used in conjunction with electrical wiring.

## BACKGROUND OF THE INVENTION

Most homes and commercial buildings utilize electrical wiring systems to distribute power throughout the structure. Typically, electrical wiring systems carry a 120 or 240 volt signal at 15 or 30 amps, respectively, to provide electrical power for lighting systems, climate control systems, appliances, and other electrical loads. Many accidents occur annually due to penetrations of electrical wires or due to deterioration of older wiring systems.

According to reports issued by the Consumer Products Safety Commission (CPSC) in 1997, home wire systems caused over 40,000 fires that resulted in 250 deaths and over $670 million of property damage. Further study by the CPSC based on 40,300 electrical circuit fires showed that 36% were due to installed wiring and 16% were due to cord/plugs.

Today, circuit breakers primarily protect against certain overload and short circuit conditions which occur primarily in fixed wiring. The overload protection is provided by the slow heating of a bimetal strip that breaks the circuit causing the breaker to trip after a specified period of time. The more current that runs through the bimetal, the shorter the time it takes to trip the breaker. Short circuit protection may be provided magnetically, that is, a high level of current may trip a breaker instantaneously. The lower limit of the magnetic trip setting may be determined by the manufacturer such that the device does not nuisance trip on high inrush loads.

Circuit breakers do not protect against all hazards that may occur within electrical wiring systems. Therefore, in addition to circuit breakers, there are many other safety devices that have been designed for use with electrical wiring. One such safety device that is commonly installed in electrical wiring systems is a Ground Fault Circuit Interrupter (GFCI). A GFCI measures the difference between the currents flowing through the hot conductor and the neutral conductor of a conventional electrical wire. If the difference between the current flowing through the hot conductor and the current flowing through the neutral conductor exceeds a few milliamps, the presumption is that current is leaking to ground via some other path. This may be because of a short circuit to, for example, the chassis of an appliance, or to the ground lead, or through a person. Any of these situations may be hazardous, so the GFCI trips, breaking the circuit.



Another safety device that is commonly installed in electrical wiring systems is an Arc Fault Circuit Interrupter (AFCI). An AFCI adds electronic protection to the standard thermal and magnetic protection provided by circuit breakers. The circuitry in an AFCI detects specific arcs that are determined to be likely to cause a fire. The AFCI uses electronics to recognize the current and voltage characteristics of the arcing faults on the electrical wire, and interrupts the circuit when a fault is detected. Each AFCI has circuit logic, and perhaps control logic, that is designed to detect specific types of arc faults. These arc faults are specific to the type of wiring the AFCI is designed to be implemented with.

A problem with many electrical wire safety devices is that they are specifically designed to be used in conjunction with conventional three-conductor electric wire. Current safety devices are not designed to be used in wiring systems that include flat electrical wire. A flat electrical wire and method of fabricating the electrical wire are described in U.S. patent application Ser. No. 10/790,055 (Now U.S. Pat. No. 7,145,073), which is incorporated by reference herein in its entirety. Flat electrical wire is designed to be a surface-mounted wiring system that can be installed on surfaces such as a wall, ceiling or floor. Accordingly, flat electrical wire is designed to be thin and flexible in order to allow it to be easily concealed, for example, by being painted or papered over. Currently existing safety devices are not specifically designed to be used in conjunction with and in many cases are incompatible with flat electrical wire. Accordingly, a need exists for one or more safety devices that are suitable for use with flat electrical wire.

Another problem with many electrical wire safety devices is that they require manual intervention and/or manual reset once a fault is detected. The electrical wire safety devices are not capable of making a determination of when a fault is no longer present on a monitored wire and, therefore, will maintain the wire in a de-energized state. This inability to determine when a fault is no longer present can lead to undesirable situations. For example, an electrical wire that provides power to a refrigerator or freezer may be de-energized by an electrical wire safety device and, if a user does not reset the safety device, perishable food items may spoil. Accordingly, a need exits for one or more improved safety devices that are capable of determining when a fault is no longer present within a monitored wire or within a portion or all of a monitored wiring system.

## BRIEF DESCRIPTION OF THE INVENTION

Embodiments of the invention include electrical safety devices and systems for use with electrical wiring, and methods for using the same. In one embodiment, a source device for use with electrical wire is provided. The source device may include a line side input, a wire connection, at least one relay, and a control unit. The line side input may be configured to connect to a line side power source and receive an electrical power signal from the line side power source. The wire connection may be configured to connect to an electrical wire. The at least one relay may be configured to control the communication of the electrical power signal onto the electrical wire. The control unit may be configured to test the electrical wire for at least one of miswires, wire faults, or abnormal conditions and, based at least in part on the results of the testing, to control the actuation of the at least one relay.

According to another embodiment of the invention, an electrical wiring system is provided. The electrical wiring system may include a source device, a destination device, and an electrical wire. The source device may be configured to be coupled to a line side power source, and the source device may include an active safety device and a first wire termination. The destination device may include a second wire termination. The electrical wire may have a first end coupled to the first wire termination and a second end coupled to the second wire termination. The active safety device may monitor the electrical wire for at least one of miswires, wire faults, or abnormal conditions and, based on the results of the monitoring, control the communication of an electrical power signal from the line side power source to the electrical wire.

According to yet another embodiment of the invention, a method for monitoring an electrical wire terminated between a source and a destination is provided. One or more conductors of the electrical wire may be tested for at least one of miswires, wire faults or abnormal conditions. The communication of an electrical power signal from a power source to the electrical wire may be controlled based at least in part on results of the testing.

Additional systems, methods, apparatus, features, and aspects are realized through the techniques of various embodiments of the invention. Other embodiments are aspects of the invention are described in detail herein and are considered a part of the claimed invention. Other advantages and features can be understood with reference to the description and drawings.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** is a schematic diagram of one example of a wiring system including an Active Safety Device (ASD), according to an illustrative embodiment of the invention.

FIG. **2**A is a cross-section view of a multi-planar, stacked, or protective layered flat wire that may be used in conjunction with an ASD, according to an illustrative embodiment of the invention.

FIG. **2**B is a cross-section view of a standard or conventional three-conductor electrical wire that may be used in conjunction with an ASD, according to an illustrative embodiment of the invention.

FIG. **3** is a block diagram of the components of an example ASD, according to an illustrative embodiment of the invention

FIG. **4**A is a block diagram of an example control unit that may be associated with an ASD according to certain embodiments of the invention.

FIG. **4**B is a flowchart of one example of the operation of the control unit of FIG. **4**A, according to an illustrative embodiment of the invention.

FIG. **5** is a schematic diagram of an example line side wire integrity component that may be incorporated into an ASD, according to an embodiment of the invention.

FIG. **6** is a flowchart of one example of the operation of a line side wire integrity component that may be incorporated into an ASD according to an embodiment of the invention.

FIG. **7** is a flowchart of one example of the general operation of a load side wire integrity component, according to an illustrative embodiment of the invention.

FIG. **8**A is one example of a timing diagram of voltage or current based test signals that may be applied by a load side wire integrity component, according to an illustrative embodiment of the invention.

FIG. **8**B is another example of a timing diagram for testing a convention wire utilizing a load side wire integrity component, according to an illustrative embodiment of the invention.

FIG. **9**A is a schematic diagram of an example voltage-based load side wire integrity component that may be incorporated into an ASD, according to an embodiment of the invention.

FIG. **9**B is a schematic diagram of an example current-based load side wire integrity component that may be incorporated into an ASD, according to an embodiment of the invention.

FIG. **9**C is a schematic diagram of an example current-based load side wire integrity component that utilizes testing relays in monitoring a wire for miswires and inter-layer shorts, according to an embodiment of the invention.

FIG. **10** is a flowchart of one example of the operation of a load side wire integrity component, according to an illustrative embodiment of the invention.

FIG. **11** is a schematic diagram of another example load side wire integrity component that may be incorporated into an ASD, according to an illustrative embodiment of the invention.

FIG. **12** is a schematic diagram of another example load side wire integrity component that may be incorporated into an ASD, according to an illustrative embodiment of the invention.

FIG. **13** is a schematic diagram of an example circuit that may be utilized to test for a wire connection at a destination module, according to an embodiment of the invention.

FIGS. **14**A-**14**F are cross-sectional views depicting an example of the dynamics of a nail or tack penetration of a live multi-planar flat wire.

FIG. **15** is a representative graph of the voltage and current waveforms present during a penetration of a flat wire by a nail as provided for in FIGS. **13**A-**13**F.

FIGS. **16**A-**16**D are cross-sectional views depicting examples of the dynamics of a penetration of a non-live multi-planar flat wire.

FIG. **17**A is a schematic diagram of one example of a source device connection to an electrical outlet and a flat wire, according to an illustrative embodiment of the invention.

FIG. **17**B is a schematic diagram of an example ASD with extender outlets, according to an illustrative embodiment of the invention.

FIG. **18** is a schematic diagram of a wire system including an Active Safety Device (ASD) that monitors two wires connected to the same destination device, according to an illustrative embodiment of the invention.

FIG. **19** is a schematic diagram of multiple destination devices in a serial configuration being supported by a single source device, according to an illustrative embodiment of an aspect of the invention.

FIG. **20** is a schematic diagram of a system in which multiple source devices form a central device that monitors multiple wires in a room, according to an illustrative embodiment of an aspect of the invention.

FIG. **21** is a schematic diagram of a network of source devices monitored by a central hub, according to an illustrative embodiment of one aspect of the invention.

## DETAILED DESCRIPTION OF THE INVENTION

The invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, embodiments of the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

As used herein, the term "relay" may refer to any suitable device, component, system, and/or combination thereof that facilitates the electrification of a wire and/or control over the electrification of a wire. Examples of relays include, but are not limited to, electrical switches, mechanical switches, electromechanical switches, electromagnetic switches, triacs, and/or any other suitable disconnection component. Additionally, for purposes of this disclosure, the terms "relay" and "disconnection component" may be utilized interchangeably.

Disclosed are systems and methods for monitoring an electrical wire or electrical wiring system for miswires and/or wire faults. An Active Safety Device (ASD) may be utilized to perform tests on an electrical wire prior to the electrification of the electrical wire, during the electrification of the electrical wire, and/or following the electrification of the electrical wire. If a miswire or wire fault is identified or detected by the ASD prior to the electrification of the electrical wire, then the electrical wire may be prevented from being electrified. If a miswire or wire fault is identified or detected by the ASD during or following the electrification of the electrical wire, then the electrical wire may be de-energized. An ASD may be utilized in many different types of applications, for example, in conjunction with commercial and/or residential wiring. As an example, an ASD may be utilized to monitor electrical wiring that is installed in a home or at a commercial or industrial site. The monitored electrical wiring may be wiring that is installed at the location at the time of construction or during a rewiring project.

Referring now to FIG. **1**, an Active Safety Device (ASD) **100** implemented in an electrical wire system **101** is shown, according to an illustrative embodiment of the invention. The electrical wire system **101** may include a source device **103**, a wire **102** that is monitored by the ASD, a line side power source **115**, a destination device **117**, and a load side destination **125**. The source device **103** may include an ASD **100** and a source module **110**. The destination device **117** may include a destination module **120** and an expansion module **122**. For purposes of the present disclosure, an ASD **100** is an electrical safety device, circuit, or module in accordance with embodiments of the invention containing reactive and/or proactive safety components, circuits, and/or circuitry, as explained in greater detail below. In some embodiments, for example, some commercial embodiments, the source device **103** and its associated components, circuitry, and modules may be designated as an ASD.

The ASD **100** may be utilized to monitor a variety of different wire types, including but not limited to, flat electrical wire, other types of flat wiring, and/or conventional electrical wiring, such as electric wire comprising elongated cylindrical conductors based on the teaching disclosed herein. For purposes of this disclosure, the term "wire" **102** is utilized to refer generally to a wire that may be monitored by the ASD **100**, irregardless of the model, type, and/or construction of the wire.

A variety of flat wires may be used in conjunction with an ASD **100** in accordance with embodiments of the invention, such as the flat wire **105** depicted in FIG. **2**A. A flat wire may be a flat electrical wire or other flat wire such as a speaker wire, telephone wire, low voltage wire, CATV wire, or under surface wire. The flat wire typically will be made up of multiple flat conductors that may be configured in a stacked, multi-planar, or protective layered arrangement or in a parallel or coplanar arrangement having conductors within the same plane. Additionally, the conductors of the flat wire may contain multiple conductive adjacent or non-insulated sublayers or flat strands. The flat wire may also contain one or more optical fibers. One example of a flat wire that may be used in association with the ASD **100** discussed herein is described in U.S. Pat. No. 7,145,073, entitled "Electrical Wire and Method of Fabricating the Electrical Wire," which is hereby incorporated by reference in its entirety. Further embodiments of the electrical flat wire are described in U.S. Pat. No. 7,217,884, entitled, "Electrical Wire and Method of Fabricating the Electrical Wire," U.S. patent application Ser. No. 11/437,992, entitled, "Electrical Wire and Method of Fabricating the Electrical Wire," U.S. patent application Ser. No. 11/932,871, entitled, "Electrical Wiring Safety Device for Use with Electrical Wire," and U.S. patent application Ser. No. 11/932,757, entitled, "Electrical Wire and Method of Fabricating the Electrical Wire," the disclosures of which are incorporated by reference herein in their entirety. Other examples of flat wires that may be used in association with the ASD **100** include, but are not limited to, the flat wires disclosed in U.S. Pat. No. 5,804,768, entitled "Flat Surface-Mounted Multi-Purpose Wire," U.S. Pat. No. 6,107,577, entitled "Flat Surface-Mounted Multi-Purpose Wire," U.S. Pat. No. 6,492,595, entitled "Flat Surface-Mounted Multi-Purpose Wire," and U.S. Pat. No. 6,774,741, entitled "Non-uniform Transmission Line and Method of Fabricating the Same," the disclosures of which are incorporated by reference herein in their entirety.

FIG. **2**A is a cross-section view of a multi-planar flat wire **105** that may be used in association with an ASD **100**, according to an illustrative embodiment of the invention. The flat wire **105** of FIG. **2**A may be an electrical flat wire with stacked conductors. At least one electrifiable conductor **205** (or hot conductor) may be situated between two return conductors **210**, **215**, (or neutral conductors) and the two return conductors **210**, **215** may be formed such that the electrifiable conductor **205** is substantially entrapped by the first and second return conductors **210**, **215**. The term substantially entrapped may be utilized to refer to a situation in which the electrifiable conductor **205** cannot be contacted by a foreign object (e.g., a nail, screw, staple, etc.) without the foreign object first contacting one of the return conductors **210**, **215**. The term substantially entrapped does not necessarily mean that the return conductors **210**, **215** completely surround the electrifiable conductor **205** (although such a design is possible). Instead, the term may mean that any distance between the return conductors **210**, **215** may be small enough that a foreign object cannot reasonably go between the return conductors **210**, **215** and the electrifiable conductor **205** without contacting one or more of the return conductors **210**, **215**.

With continued reference to FIG. **2**A, two grounding conductors **220**, **225** may be included in the flat wire **105**. The various conductors of the flat wire **105** may be assembled in a stacked configuration such that the electrifiable conductor **205** is situated between the two return conductors **210**, **215** and that three conductor arrangement is then sandwiched between the two grounding conductors **220**, **225**. This configuration may be referred to as a G-N-H-N-G configuration.

Additionally, insulation material may be disposed between each of the conductors of the flat wire **105**. The insulation material may prevent the various conductors of the flat wire **105** from contacting one another and creating a short circuit in the flat wire **105**. Electrifiable conductor insulation material **230** may surround the electrifiable conductor **205** and prevent the electrifiable conductor **205** from making electrical contact with the other conductors of the flat wire **105**. Additionally, return conductor insulation material **235** may be disposed between the return conductors **210**, **215** and the corresponding grounding conductors **220**, **225** to prevent the first return conductor **210** from contacting the corresponding first grounding conductor **220** and to prevent the second return conductor **215** from contacting the corresponding second grounding conductor **225**. Grounding conductor insulation **240** may be disposed opposite the first grounding conductor **220** and the second grounding conductor **225**, and the grounding conductor insulation **240** may prevent the grounding conductors **220**, **225** from contacting an object or surface that is external to the flat wire **105**.

Alternatively, each conductor of the flat wire **105** may be individually wrapped with an insulation material. In this alternative configuration, electrifiable conductor insulation material **230** would be disposed on both sides of the electrifiable conductor **205** to separate the electrifiable conductor **205** from the return conductors **210**, **215**. Return conductor insulation material **235** would be disposed on both sides of each of the return conductors **210**, **215** to separate the return conductors **210**, **215** from the electrifiable conductor **205** and the grounding conductors **220**, **225**. Grounding conductor insulation material **240** would be disposed on both sides of each of the grounding conductors **220**, **225** to separate the grounding conductors **220**, **225** from the return conductors **210**, **215** and any objects or surfaces that are external to the flat wire **105**. In the alternative configuration, two layers of insulation material are disposed between any two conductors of the flat wire **105**, thereby decreasing the possibility of short circuits between the conductors of the flat wire **105**. In other words, a short circuit between two conductors of the flat wire **105** exists when there is a flaw in the insulation material between the two conductors. For example, if only a single layer of insulation material is disposed between each of the conductors of the flat wire **105**, a short circuit might occur if there is a flaw in the insulation material disposed between the electrifiable conductor **205** and one of the return conductors **210**. If, however, each of the conductors of the flat wire **105** is individually wrapped with insulation material, the possibility of a short circuit between two conductors is decreased because flaws would need to be present in both layers of insulation material disposed between the two conductors, and the flaws would need to line up with one another or be situated in close proximity to one another. For example, for a short circuit to occur between the electrifiable conductor **205** and one of the return conductors **210**, flaws must be present in both the electrifiable conductor insulation material **230** and in the return conductor insulation material **235** disposed between the two conductors. Additionally, these flaws would need to line up with one another or be situated in close proximity to one another.

Although a five-conductor stacked flat wire is depicted in FIG. **2**A, the ASD **100** may be utilized to monitor flat wires with many different conductor configurations. For example, flat wires with a wide variety of stacked conductor configurations may be monitored by the ASD **100**. As an example, a three conductor flat wire having a stacked configuration may be monitored by the ASD **100**. The three conductor flat wire may include an electrifiable conductor that is substantially entrapped by first and second return conductors, and the three conductor configuration may be referred to as a N-H-N configuration. Additionally, various flat wire embodiments containing parallel or coplanar arrangements of conductors may be monitored by the ASD **100**. For example, a three conductor flat wire having a coplanar arrangement may be monitored by the ASD **100**. The three conductor coplanar flat wire may include an electrifiable conductor, a return conductor, and a grounding conductor disposed in a parallel configuration within the same plane.

In addition to various types of flat wire, the ASD **100** may be utilized to monitor other types of wire, including round wires and/or wires having a concentric or substantially concentric arrangement of conductors. FIG. **2**B is a cross-section view of a standard three-conductor electrical wire, discussed herein as a conventional wire **107**, that may be used in conjunction with an ASD **100**, according to an illustrative embodiment of the invention. With reference to FIG. **2**B, the conventional wire **107** may include an electrifiable or hot conductor **250**, a return, neutral, or grounded conductor **255**, and a grounding or ground conductor **260**. Suitable insulation material may be wrapped around or provided for the electrifiable conductor **250** and the return conductor **255**. As shown in FIG. **2**B, electrifiable conductor insulation material **265** may be provided for the electrifiable conductor **250** and return conductor insulation material **270** may be provided for the return conductor **265**. The grounding conductor **260** may not contain its own individual insulation; however, suitable insulation material, such as thermoplastic insulation, may be provided for all three of the conductors **250**, **255**, **260** of the conventional wire **107**.

FIG. **2**B illustrates a typical construction for an electrical wire; however, electrical wires having constructions that vary from that shown in FIG. **2**B may be utilized in association with an ASD **100** in accordance with various embodiments of the invention. The conventional wire **107** illustrated in FIG. **2**B and its construction is provided merely to depict one example of a wire that may be utilized in association with an ASD **100** in accordance with certain embodiments of the invention.

With reference back to FIG. **1**, in a wire system **101**, a wire **102** may be connected to the ASD **100** through a source module **110**. The source module **110** may be physically separate from the ASD **100**, or alternatively, the source module **110** may be integrated into the ASD **100**. The source module **110** may serve as a mechanical or electromechanical connection between the wire **102** and the ASD **100**. The various conductors of the wire **102**, may be terminated at the source module **110**. Termination points within the source module **110** may include terminal blocks, crimp-on terminals, plug and socket connectors, insulation displacement connectors (IDC), conductor penetration connectors (CPC), or any other suitable electrical connector as combination of electrical connectors. One or more appropriate detection devices may be utilized to verify that the source module **110** is connected to the ASD **100** and/or that the termination points are connected to the source module **110**. For example, a ground pin or plug may be extended through the source module **110** and/or the termination points in order to detect the presence of the source module **110** and/or the termination points. As another example, an optical detection device may be utilized. Furthermore, a combination of detection devices may be utilized as desired in certain embodiments.

The ASD **100** may also be connected to a line side power source **115**. The line side power source **115** may be any standard electric power source including a power wire coming from a circuit box, a conventional in-wall electrical wire, a flat electrical wire, or any other electrical wire capable of delivering electric power. For flat wire **105** and/or conventional wire **107** branch circuit applications, the line side power source **115** may be a typical wall-mounted or in-wall power outlet or power receptacle. Typically, the line side power source **115** will carry an electrical voltage of approximately 110-130 VAC or approximately 220-250 VAC.

The line side power source **115** may be physically separate from the source device **103** or, alternatively, the line side power source **115** may be integrated into the source device **103**. For example, if a conventional in-wall electrical wire were directly connected to the source device **103**, the line side power source **115** would be physically separate from the source device **103**. Alternatively, the line side power source **115** may be integrated into the source device **103** in a situation in which the source device **103** includes, for example, a conventional three-prong plug that may be inserted into a standard electrical outlet.

Still referring to FIG. **1**, the wire **102** may create a connection between the source module **110** and one or more destination devices **117**. The one or more destination devices **117** may include a destination module **120** and an expansion module **122**. Much like the source module **110**, a destination module **120** may serve as a mechanical or electro-mechanical connection between the wire **102** and the destination device **117**. The various conductors of the wire **102** may be terminated at the destination module **120**. Termination points within the destination module **120** may include terminal blocks, crimp-on terminals, plug and socket connectors, insulation displacement connectors (IDC), conductor penetration connectors (CPC), or any other suitable electrical connector or combination of electrical connectors.

An expansion module **122** may be included in a destination device **117**, and the expansion module **122** may serve as a mechanical or electro-mechanical connection between the destination device **117** and a load side destination **125**. A load side destination **125** may include a power outlet or receptacle, a wired device, a terminal block, a safety component, "flying leads," or any other suitable load side connection as desired in various embodiments. Termination points within the expansion module **122** used to connect the load side destination **125** to the expansion module **122** may include terminal blocks, crimp-on terminals, plug and socket connectors, insulation displacement connectors (IDC), conductor penetration connectors (CPC), or any other electrical connector as desired in various embodiments. Additionally, in certain embodiments of the invention, the load side destination may be connected to the destination module **120** as an alternative to being connected to the expansion module **122**.

The load side destination **125** may be physically separate from the destination device **117** or, alternatively, the load side destination **125** may be integrated into the destination device **117**. For example, if an electrical device such as a lamp were directly connected to the destination device **117**, the load side destination **125** would be physically separate from the destination device **117**. Alternatively, the load side destination **125** may be integrated into the destination device **117** in a situation in which the destination device **117** includes, for example, one or more electrical sockets. The destination device **117** may include any number of electrical sockets configured to receive electrical plugs. For example, the destination device **117** may include one, two, three, or four sockets that serve as a load side destination **125**.

Additionally, the expansion module **122** may be used to create a mechanical or electro-mechanical connection between the destination device **117** and a second destination device, as explained in greater detail below with reference to FIG. **19**. In such an embodiment, a second wire **102** may be, for example, connected to the expansion module **122** and used to create a connection between the expansion module **122** and the second destination device. Termination points within the expansion module **122** may include terminal blocks, crimp-on terminals, plug and socket connectors, insulation displacement connectors (IDC), conductor penetration connectors (CPC), or any other electrical connector as desired in various embodiments.

Additionally, as explained in greater detail below, the destination device **117** may be capable of communicating with the ASD **100** through the source module **110** over one or more suitable conductors of the wire **102**. The destination device **117** may also be capable of communicating with a second destination device through the expansion module **122** over a second wire **102**, as explained in greater detail below with reference to FIG. **19**.

FIG. **3** is a block diagram of the components of a source device **103**, according to an illustrative embodiment of the invention. The ASD **100** may include a line side input **305**, one or more relays **310**, a wire I/O interface **311**, a control unit **312**, and various safety components including one or more of a GFCI component **315**, an AMC and/or AFCI component **320**, an over-current protection component **325**, a ground current monitoring component **330**, a line side wire integrity component **335**, and a load side wire integrity component **340**.

The ASD **100** may be powered by a power source, which may be connected to the ASD **100** at the line side input **305**. For example, the line side power source **115** may be connected to the line side input **305** of the ASD **100** to provide power to the ASD **100**. Further, the one or more relays **310** may control the flow of an electrical signal, which may be an electrical power signal, from a power source through the ASD **100** to the source module **110**. Each of the one or more relays **310** may be, for example, a double pole single throw (DPST) relay. As desired, a multitude of other relays and/or types of relays may be used by the ASD **100** including, but not limited to, one or more single pole single throw (SPST) relays, one or more single pole double throw (SPDT) relays, one or more single pole changeover or center off relays (SPCO), one or more double pole double throw relays (DPDT), or one or more double pole changeover or center off relays (DPCO).

The ASD **100** may include a single (common or main) relay **310** or it may include multiple relays in other suitable configurations within the ASD **100**. For example, each safety component of the ASD **100** may include subordinate or dedicated relays or, alternatively, various components of the ASD **100** may share a common or main relay **310**. As another example, a separate relay may be provided for various conductors of a wire **102** that is connected to the source module **110**. For example, if an electrical flat wire **105** as illustrated in FIG. **2A** is connected to the source module, a first relay may be provided for the electrifiable conductor **205** and a second relay may be provided for the return conductors **210**, **215**. As another example, if a conventional electrical wire **107** as illustrated in FIG. **2B** is connected to the source module, a first relay may be provided for the electrifiable conductor **250** and a second relay may be provided for the return or neutral conductor **255**.

Each of the relays may be actuated independently of one another or, alternatively, a plurality of the relays may be jointly actuated. The ASD **100** may utilize one or more relays to communicate test signals onto the wire **102** without providing an electrical power signal to the electrifiable conductor, such as conductor **205**, of the wire **102**. For example, as explained in greater detail below with reference to a flat wire in FIG. **11**, the second relay may be utilized to communicate a test signal onto the return conductors **210**, **215** of the flat wire **105**, and the ASD **100** may then monitor the flat wire **105** for miswires and/or wire faults. If the ASD **100** determines that no miswires and/or wire faults exist on the flat wire **105**, then the ASD **100** may utilize the first relay to permit an electrical power signal to be communicated onto the electrifiable conductor **205**. As another example, the second relay may be utilized to communicate a test signal onto the return conductor **255** of a conventional wire **107** while a first relay may be utilized to communicate a test signal onto the electrifiable conductor **250** of the conventional wire **107**. The ASD **100** may then monitor the conventional wire **107** for miswires and/or faults. Unless otherwise stated in this disclosure, for purposes of simplicity, reference will be made to an ASD **100** that includes a single relay **310** that is utilized to control the communication of an electrical power signal onto the electrifiable conductor, such as **205** or **250** of a wire **102**.

In the illustrative embodiment with a single relay **310**, also referred to as the common or main relay, the ASD **100** may maintain the relay **310** in either an opened position or a closed position. When the relay **310** is maintained in a closed position, electrical power may be permitted to flow from a line side power source **115** through the ASD **100** to the source module **110**. As shown in FIG. **3**, an ASD power line **350** may be included in the ASD **100** to carry the electrical power from the line side input **305** through the ASD **100** to the source module **110**; however, in certain embodiments of the invention, the electrical power could be propagated through the ASD **100** via circuitry other than an ASD power line **350**, such as through the various individual safety components of the ASD **100**. The ASD power line **350** is included in this disclosure for simplification purposes in order to facilitate the understanding of the invention. From the source module **110**, the electrical power may then be transmitted onto the wire **102** and be delivered to the destination module **120**.

Alternatively, when the relay **310** is maintained in an opened position, an electrical signal is not allowed to flow from a line side power source **115** through the ASD **100** to the source module **110**. The ASD **100** may beneficially be configured to default to maintaining the relay **310** in an opened position. By defaulting to an opened position, the ASD **100** may ensure that no faults are present in the wire system **101** prior to full electrification or energization of the wire system **101**. Accordingly, whenever the ASD **100** loses power, if the relay **310** is not in an opened position, the relay **310** may be switched to an opened position in order to permit the ASD **100** to perform tests on the wire system **101**.

According to an aspect of the invention, the relay **310** may be part of a zero crossing circuit. Alternatively, the zero crossing circuit may be a part of the control unit **312**, and the control unit **312** may receive a power signal, such as an alternating current power signal, from the line side input **305** and provide a coil control signal (such as a 120 VAC, 24 VDC or 12 VDC signal) to the relay **310**. A zero crossing circuit is an electrical circuit that detects an alternating current load voltage at or close to zero phase occurring once for each alternating current half cycle. The zero crossing circuit may be used in connection with the opening or closing of the relay **310** in order to assist in opening or closing the relay **310** at a point in time that is close to the zero phase of the input signal. Zero crossing circuits may work on voltage zero crossings or on current zero crossings. The zero crossing circuit may take inherent turn-on and turn-off delays associated with the relay **310** into account when making zero crossing contact closures or breaks of the main relay **310**. Since typical power systems in many countries run at 60 cycles per second or Hertz (Hz), a zero crossing occurs approximately every 8.3 milliseconds (ms). A typical relay **310** may have, for example, a 5 millisecond actuation time (closing time) and a 3 millisecond break time (opening time). In this example, for zero crossing turn-on, the relay coil must be energized for 3.3 ms (or the 8.3 ms cycle time−the 5 ms actuation time) after the last zero crossing of the input signal to produce a contact closure (actuation) of the relay **310** at the next zero crossing of the input signal. Similarly, in the same example, the relay coil must be de-energized for 5.3 ms (or the 8.3 ms cycle time−the 3 ms break time) after the last zero crossing to produce a contact break (de-actuation or opening) at the next zero crossing of the input signal. Accordingly, the output of power from the ASD **100** onto the wire **102** will start as soon as possible once the relay **310** is closed. Additionally, the input waveform from the line side **115** will match the output waveform across the wire **102** as closely as possible meaning that less energy is dissipated in the ASD **100** and source module **110** circuitry. The ability of the ASD **100** to perform a zero cross turn on or turn off of the relay **310** may extend the lifetime of the contacts in the relay **310**, limit the contact arc-showering effect, limit electromagnetic emissions, and limit conducted electrical noise from the relay **310**.

According to another aspect of the invention, the relay **310** may be actuated for a relatively short period of time in which tests may be performed on the wire **102**. For example, the relay **310** may be actuated for a period of time that is less than or approximately equal to the time that it takes for one half of a typical power cycle. As explained in greater detail below with reference to FIGS. **9**, **11** and **12**, the ASD **100** may test one or more conductors of the wire **102** during the time that the relay **310** is actuated.

According to another aspect of the invention, the ASD **100** may be able to detect slow breaking (i.e., sticky) contacts in the relay **310**. The control unit **312** of the ASD **100** may monitor the contact break times of the relay **310** with a counter or other timing device. The control unit **312** may directly monitor the break time of the relay **310**, or the control unit **312** may monitor the break time of the relay **310** by receiving information from the wire I/O interface **311**. By monitoring the break time of the relay **310**, the control unit **312** may detect a slow break time for the relay **310**. For preventative maintenance purposes, the ASD **100** may alert a user of these slow breaking contacts so that the ASD **100** may be repaired or replaced. The user may be alerted in a number of ways by the ASD **100**. One possible method for alerting a user is to activate an LED on the exterior of the ASD **100** that will alert the user to the potential main relay contact problems. Another method for alerting the user is to transmit a communication from the ASD **100** to either another ASD **100**, a central hub or control panel, or some other device, as will be explained in greater detail below with reference to FIGS. **19-20**.

According to another aspect of the invention, the ASD **100** may include a control unit **312**. The control unit **312** may control the various safety components of the ASD **100**. Alternatively, each individual safety component of the ASD **100** may include its own control unit or various components of the ASD **100** may share control units. The control unit **312** may contain one or more microcontrollers and associated components such as resistors, diodes, capacitors, and crystals or, alternatively, the control unit **312** may be any other suitable device and associated circuitry for controlling an electronic circuit including, but not limited to, microprocessors, one or more programmable logic arrays, a state machine, a minicomputer, or a general purpose computer along with any associated firmware and software. The execution of programmable logic and/or software components by one or more processors of the control unit **312** may form a special purpose machine or a particular machine that is operable to monitor the wire **102** and/or control the electrification of the wire **102**. As desired, many different types of control units may be incorporated into, associated with, or in communication with the ASD **100**. Additionally, a control unit may include any number of processors. A control unit may also be external to and/or located remotely to the ASD **100**, and the control unit may communicate with the components of the ASD **100** via a suitable network connection, for example, a wired network connection or a wireless network connection.

According to an aspect of the invention, the control unit **312** may be configured to or operable to store various types of data associated with the operation of the ASD **100**. The data may include data associated with the operation of the various safety components of the ASD **100**. Additionally, the data may include measurements data that has been taken while monitoring the wire **102** in accordance with the operation of the various safety components of the ASD **100**. The data may also include one or more counters associated with the operation of the ASD **100** and the various safety components of the ASD **100**. For example, the data may include a number of counters that the ASD **100** and/or the various safety components of the ASD **100** has recognized a miswire or wire fault on wire that is monitored by the ASD **100**. The stored data may be utilized during subsequent operations of the ASD **100**. For example, data stored in associated with the operation of a safety component of the ASD **100** may later be utilized in association with the operation of the safety component of the ASD **100** and/or in association with the operation of other safety components (or the control unit **312**) of the ASD **100**. A wide variety of data may be stored by the ASD **100** or by one or more memory devices associated with the ASD **100** as desired in various embodiments. The data items that may be stored by the ASD **100** include, but are not limited to those listed in Table 1 below:

TABLE 1

Data Items that may be Stored

| Data Item | Type | Initial Value |
|---|---|---|
| Hot Relay Normal Actuations Count | counter | 0 |
| Hot Relay Normal Actuations limit for end of life | limit | 75000 |
| Hot Relay High Current Actuations Count | counter | 0 |
| Hot Relay High Current Actuations Limit for end of life | limit | 5 |
| Fatal non-resetable (internal) Fault Code | code | 0 |
| Non-fatal Limited Resetable Fault Count | counter | 0 |
| Non-fatal Unlimited Resetable Fault Count | counter | 0 |
| Hot Relay Actuation Time | value | 0 |
| Hot Relay Release Time | value | 0 |
| Fault code #1 count | counter | 0 |
| Fault code #2 count | counter | 0 |
| Fault code #3 count | counter | 0 |
| Fault code #4 count | counter | 0 |
| Fault code #5 count | counter | 0 |
| Fault code #6 count | counter | 0 |
| Fault code #7 count | counter | 0 |
| Fault code #8 count | counter | 0 |
| Fault code #9 count | counter | 0 |
| Fault code #10 count | counter | 0 |
| Fault code #11 count | counter | 0 |
| Fault code #12 count | counter | 0 |
| Fault code #13 count | counter | 0 |
| Fault code #14 count | counter | 0 |
| Fault code #15 count | counter | 0 |
| Fault code #16 count | counter | 0 |
| Fault code #17 count | counter | 0 |
| Fault code #18 count | counter | 0 |
| Fault code #19 count | counter | 0 |

Other data items may be stored by the ASD **100** as desired in various embodiments of the invention. Additionally, in certain embodiments of the invention, the initial values of one or more of the data items may be different than those listed in Table 1. With reference to Table 1, the Hot Relay Normal Actuations Count may keep track of the number of times that the relay **310** is actuated during the normal course of the operation of the ASD **100**; the Hot Relay Normal Actuations Limit may establish a limit for the normal actuations of the relay **310** during the lifetime of the ASD **100**; the Hot Relay High Current Actuations Count may keep track of the number of times that the relay **310** is tripped as a result of a high current event, as explained in greater detail below with reference to FIG. **4**A; the Hot Relay High Current Actuations Limit for end of Life parameter may establish a limit for the number of high current actuations of the relay **310** during the lifetime of the ASD **100**, as explained in greater detail below with reference to FIG. **4**A; the Fatal Non-Resetable Fault Code may establish a code to be stored for any identified Fatal Non-Resetable Faults; the Non-fatal Limited Resetable Fault Count may keep track of the number of Non-fatal Limited Resetable Faults that are identified; the Non-fatal Unlimited Resetable Fault Count may keep track of the number of Non-fatal Unlimited Resetable Faults that are identified; the Hot Relay Actuation Time Parameter may establish a value for the time that it takes to actuate the relay **100**; the Hot Relay Release Time Parameter may establish a value for the time that it takes to release the relay **100**; and the parameters for Fault Codes 1-19 Counts may keep track of the number of different types of faults that are identified by the ASD **100**.

Many different types of faults may be identified as desired in various embodiments of the invention. Each fault may be associated with its own counter. Additionally, the tracking of faults in one or more memories and/or control units **312** associated with the ASD **100** may facilitate post mortem failure analysis and/or detections of abuse or misuse of an ASD **100**. As one example, an ASD **100** may track the number of GFCI trips, overcurrent trips, self test failures, and/or other types of identified faults as desired. The tracking of these various types of faults may then be utilized in a determination of the reasons that a lifetime counter (as discussed below with reference to FIG. **4**A) of the ASD **100** has been reached. Additionally and/or alternatively, the tracking of these various types of faults may be utilized in a determination of abuse or misuse of an ASD **100**, such as overloading a circuit.

The ASD **100** may utilize one or more values and/or parameters stored in memory during the monitoring of a wire **102**. The ability to store values and/or parameters in a memory of the ASD **100** may facilitate additional monitoring capabilities of the ASD **100**. For example, the use of a memory may facilitate the continued monitoring of a wire **102** in which a fault has been identified in order to determine whether the fault is still present on the wire. In this regard, the ASD **100** may determine if and when a fault is no longer present on a monitored wire **102** and re-energize the wire **102** when the fault is no longer present.

As an example, an ASD **100** may be utilized to monitor an energized wire **102**, such as a flat wire **105** or a conventional wire **107**. If a fault is detected on the wire **102**, then the relay **310** of the ASD **100** may be opened and the wire **102** may be de-energized. One or more flags may be set within the memory of the ASD **100** indicating that a fault has been detected on the wire **102** while the wire was energized. While the one or more flags are set, the ASD **100** may continually or periodically test the wire **102** in order to determine whether the fault is still present on the wire **102**. For example, the ASD **100** may test the wire **102** every ten minutes or every hour (or at any other desired time interval) in order to determine whether the fault is still present on the wire **102**. If, at any time, it is determined that the fault is no longer present on the wire **102**, then the relay **310** of the ASD **100** may be closed, allowing the wire **102** to be re-energized.

The ability to automatically test a wire **102** in which a fault has been previously identified may allow electrical devices that are connected downstream from the wire **102** to receive power again after it has been determined that a fault is no longer present on the wire **102**. Additionally, these downstream devices may receive power without any user actions being taken in association with the wire **102** and/or ASD **100**. For example, a fault, such as a ground fault, may be identified in a wire **102** that supplies power to a refrigerator. It may later be determined that the fault is no longer present on the wire **102**, and the wire **102** may be re-energized, thereby allowing the refrigerator to receive power again. The refrigerator may receive power again without any user interaction, such as a user resetting a conventional GFCI device.

FIG. **4**A is a block diagram of one example of a control unit **312** that may be associated with an ASD **100** according to certain embodiments of the invention. The control unit **312** may include one or more suitable memory devices **405** and one or more processors **410**. Any number of suitable memory devices **405** may be utilized as desired in embodiments of the invention, for example, caches, read only memories, random access memories, magnetic storage devices, etc. The memory devices **405** may store programmed logic **415** (e.g., software code) in accordance with various embodiments the invention. The memory devices **405** may also include measurements data **420** utilized in the operation of the invention, counters or states utilized in the operation of the invention **422**, and an operating system **425**. The one or more processors **410** may utilize the operating system **425** to execute the programmed logic **415**, and in doing so, may also utilize the measurement data **420**. The programmed logic **415** may include the logic associated with the operation of the one or more safety components of the ASD **100**. Execution of the programmed logic **415** by the one or more processors **410** may form a special purpose computer or a particular machine that facilitates the control the ASD **100**, the monitoring of a wire **102** connected to the ASD **100**, and/or the electrification of the wire **102**. A data bus **430** may provide communication between the memory devices **405** and the one or more processors **410**. The control unit **312** may be in communication with the other components of the ASD **100** and perhaps other external devices, for example, lights, light emitting diodes (LED's), LED displays, other displays, speakers, keyboards, mouse devices, and other user interface devices, as well as data lines connected to other ASD's or electrical appliances, via an I/O Interface **440**. Additionally, measurement devices configured to take various electrical measurements of the wire **102** may be in direct communication with the control unit **312** via a measurement devices interface **450** or, alternatively, may communicate with the control unit **312** via the I/O Interface **440**. These measurement devices may be included in the wire I/O interface **311**, as described in greater detail below. Further, the control unit **312** and the programmed logic **415** implemented thereby may comprise software, hardware, firmware or any combination thereof.

The control unit **312** may control and/or include the various safety components of the ASD **100**. Additionally, the control unit **312** may store data relating to the status of the wire system **101**. For example, the control unit **312** may maintain flags or states for each of the safety components of the ASD **100** in order to determine when to trip the relay **310** of the ASD **100** and to indicate, in the event of a miswire or fault detection, which safety component identified the wire **102** miswire or fault. The control unit **312** may also store measurements data **420** associated with the operation of the various safety components of the ASD **100**. In addition, before the relay **310** of the ASD **100** is closed, allowing a wire **102** to be electrified, the control unit **312** may cause each safety component to test the wire **102** for miswire and/or wire faults. The control unit **312** may also be configured to take a control action when a miswire or wire fault in the wire **102** is detected. A control action may include, in addition to maintaining or forcing the relay **310** into its open position, an action that informs a user of the ASD **100** about the miswire or fault detection. For example, a visual indicator such as an LCD display or one or more LED's may be included in the ASD **100**, and the display or LED's may be actuated in such a manner as to inform a user of the miswire or fault detection and the nature of the miswire or fault detected. As one example, the ASD **100** may include a single LED that is activated by the control unit **312** when a fault is detected to inform a user of the fault. As an alternative example, the ASD **100** may include an LED associated with each safety component of the ASD **100** and, when a miswire or fault is detected, the control unit **312** may activate the LED associated with the safety component that detected the miswire or fault. Another control action that may be taken by the control unit **312** is the transmission of a message indicating the detection of the miswire or fault. The control unit **312** may transmit the message to another ASD **100**, to a central hub or control panel, or to another destination, as will be explained in greater detail below. Other indicators, such as audible alarms, may additionally or alternatively be utilized by the ASD **100** as desired in various embodiments of the invention. Indicators that may be used by the ASD **100** beneficially add to the overall safety of the ASD **100** by informing a user of a fault and potentially pinpointing the fault for the user.

The control unit **312** may also include one or more counters and/or timers **422**. Counters and/or timers **422** associated with each safety component may be used by the control unit **312** to track the number of times a particular safety component has detected a miswire or wire fault in the wire **102**. Additionally, a universal timer or counter may be used to track the number of times the ASD **100** has detected a miswire or wire fault in the wire system **101**. Separate counters may also be utilized to track detected miswires and detected wire faults. These counters and/or timers **422** may be used to monitor the wire system **101**, and may be used to generate states that indicate the current condition of the wire system **101**. The counts and/or states may be used to perform preventive maintenance on the wire system **101**. The storage capability of the counters and/or timers **422** may also be non-volatile, for example, in non-volatile memory, so that information including counts and states are not lost during a power outage or brown-out condition.

According to an aspect of the invention, the control unit **312** may additionally include at least one lifetime counter. In certain embodiments, the relay **310** may have a lifetime associated with it. In other words, the relay **310** may cease to operate properly after it has been actuated normally for a certain number of times or after it has been tripped several times as the result of a detected high current event. For normal actuations of the relay **310**, the lifetime of the relay may be a relatively large value, for example, the value shown for the Hot Relay Normal Actuations Limit for End of Life parameter of Table 1. For the number of trips due to detected high current events, a predicted lifetime of the relay **310** may be similar to a mean trips to failure for the relay **310**, for example, the value shown in the Hot Relay High Current Actuations Limit for end of Life parameter of Table 1. Different types of relays **310** that may be utilized by the ASD **100** may be associated with different lifetimes. A lifetime counter associated with a relay **310** may be configured to count down from or up to a predetermined threshold value. The threshold value may be a value that is less than or equal to the predicted lifetime of the relay **310**. For example, if the predicted lifetime of the relay is 8-10 trips, then the threshold value may be established as 5 trips of the relay **310**. Once the relay **310** has been tripped a number of times equal to the threshold value, the ASD **100** may deactivate the relay **310** and prevent the relay **310** from being closed by a user event, for example, a reset of the ASD **100**. Utilizing the example of the relay **310** with a threshold value established as 5 trips, a user may reset an ASD **100** and the relay **310** following the first four trips of the relay **310**; however, once the relay **310** has tripped for the fifth time, a user will not be permitted to reset the ASD **100** and the relay **310**. In such a situation, the user may be required to return or send the ASD **100** to a retailer, distributor, manufacturer, or repair center associated with the ASD **100** in order to have the relay **310** and/or the ASD **100** tested, updated, and/or replaced. The lifetime counter may prevent a situation in which the ASD **100** and the relay **310** is reset, but the relay **310** is not capable of tripping when a miswire or wire fault is detected by the ASD **100**.

According to an aspect of the invention, each of the one or more lifetime counters of the ASD **100** may be associated with specific types of errors detected by the ASD **100**. For example, the lifetime counter may be associated with errors that lead to a tripping of the relay **310** due to a high current event, thereby causing an electrified wire **102** to be de-energized. In certain embodiments, not all errors detected or detectable by the ASD **100** will lead to a tripping of the relay **310** as a result of a high current event. For example, an error detected prior to the electrification of the wire **102** may not lead to a tripping of the relay **310**. According to an aspect of the invention, there are three different types of exceptions or alarms that may be recognized by the ASD **100**. The first type of alarm is a fatal non-resetable alarm, which may be recognized if a failure of any of the internal circuitry of the ASD **100** is detected. For example, a fatal non-resetable alarm may be recognized if a stuck relay is identified, if a fuse incorporated into the ASD **100** is blown, if a detected signal is outside of a detectable range, if a failure of self-test circuitry associated with the ASD **100** is detected, and/or if a lifetime counter has exceeded or reached a threshold value. The second type of alarm is a non-fatal limited resetable alarm, which may be an alarm that is associated with a high current event on the wire **102**. For example, a non-fatal limited resetable alarm may be recognized if a wire fault is detected on an electrified wire **102**. The third type of alarm may be a non-fatal unlimited resetable alarm, which may be associated with a non-fatal alarm that does not involve a high current event. In certain embodiments, the ASD **100** may allow an unlimited number of the third type of alarm to occur; however, as desired, a limit may be associated with this type of alarm. An ASD **100** in accordance with embodiments of the invention may recognize many different types of alarms and that those alarms described herein are merely examples of various types of alarms and should not be construed as limiting.

FIG. **4**B is a flowchart of one example of the general operation of the ASD **100** of FIG. **3** and the control unit **312** of FIG. **4**A, according to an illustrative embodiment of the invention. The operations described in FIG. **4**B may include the operations that are performed to monitor a wire **102** by the ASD **100**. At block **455**, power may be applied to the ASD **100**, and the ASD **100** may commence operation at block **460**. At block **460**, the ASD **100** may test the line side **115** for miswires. If a line side miswire is detected at block **465**, then the ASD **100** may go to block **470** and prevent the relay **310** from being closed, thereby preventing the electrification of the wire **102**. If, at block **465**, no line side miswires are detected by the ASD **100**, then the ASD **100** may go to block **475** and test the load side wire **102** and/or any other wires or devices connected on the load side for miswires and/or wire faults. If, at block **480**, a miswire or wire fault is detected on the wire **102**, then the ASD **100** may go to block **470** and prevent the relay **310** from being closed, thereby preventing the electrification of the wire **102**. If, however, at block **480**, no miswires and/or wire faults are detected on the wire **102**, then the ASD **100** may go to step **485**. At lock **485**, the relay **310** of the ASD **100** may be closed, and the wire **102** may be electrified. During the electrification of the wire **102** and/or after the wire **102** has been electrified, the ASD **100** may monitor the wire **102** and/or any other wires or devices connected on the load side for wire faults at block **490**. If a fault is detected on the wire **102** or on the load side at block **495**, then the ASD **100** may go to block **470** and open the relay **310**, thereby causing the wire **102** to be de-electrified or de-energized. If, however, no wire faults are detected on the wire **102** or on the load side at block **495**, then the ASD **100** may go to block **490** and continue monitoring the wire **102**.

The method depicted in FIG. **4**B may be applicable to the monitoring of any type of wire, including electrical flat wire and/or conventional wire. Additionally, the tests performed by the control unit **312** do not necessarily have to be performed in the order set forth in the logic of FIG. **4**B, but instead may be performed in any suitable order. Additionally, the control unit **312** does not have to conduct each test set forth in FIG. **4**B, but instead may conduct less than all of the tests set forth in FIG. **4**B. Additionally, if a miswire or wire fault is detected by the control unit **312** or by a safety component in communication with the control unit **312**, then an indicator may be stored by the control unit **312** or the associated safety component, and the indicator may include information as to which test(s) resulted in the detection of the miswire or wire fault. This indicator may then be transmitted by the ASD **100** to another device such as a second ASD **100**, a central monitoring device, or a computer.

As mentioned earlier, the ASD **100** may include both reactive and/or proactive safety components. A reactive safety component of the ASD **100** may detect a wire fault in the wire **102** after the wire **102** has been fully electrified. A reactive safety component may also detect a wire fault during the full electrification of the wire **102** or during the time period that it takes to fully electrify the wire **102** after a full electrification signal is allowed to flow onto the wire **102**. In other words, a reactive safety component may detect wire faults while a voltage in the range of approximately 90 to 130 VAC (for a standard 120 VAC power system, such as a North American power system) or a voltage in the range of approximately 220 to 250 VAC (for a standard 240 VAC power system, such as a European power system) is present on the electrical wire **102**. Each country or region may have differing voltage or current standards that may be taken into account in the design and implementation of the ASD **100**. Additionally, in certain embodiments of the invention, one or more reactive tests may be conducted constantly following the electrification of the wire **102**. Alternatively, one or more reactive tests may be conducted periodically following the electrification of the wire **102**.

A proactive safety component of the ASD **100** may detect a wire fault prior to full power electrification of the wire **102**. In other words, a proactive safety component may perform checks or tests on the electrical wire **102**, for example, checks or tests that involve the communication of voltage or current test signals onto the wire **102**, prior to allowing full electrification of the wire **102**.

Reactive safety components of the ASD **100** may include one or more of a ground fault circuit interrupter (GFCI) **315**, an arc mitigation circuit (AMC) and/or an arc fault circuit interrupter (AFCI) **320**, an over-current protection component **325**, and a ground current monitoring component **330**. Proactive safety components of the ASD **100** may include one or more of a line side wire integrity component **335** and a load side wire integrity component **340**. Each of these safety components is discussed in greater detail below.

The reactive and proactive safety components of the ASD **100** may utilize various electrical measurements associated with line side and/or load side conventional wiring, such as wire **107**, as well as line side and/or load side flat wire, such as flat wire **105**, that is connected to the line side input **305** of the ASD **100** and to the source module **110** in determining whether or not a miswire condition or wire fault exists on either side of the ASD **100**. The ASD **100** may utilize the various measurements to detect miswires on the line side of the ASD **100** and to detect miswires and/or wire faults on the wire **102** that is connected on the load side of the ASD **100**. The ASD **100** may include a wire I/O interface **311** that is capable of taking electrical measurements associated with the various conductors of the wire **102** connected to the ASD **100**. Alternatively, these electrical measurements may be taken by the various components of the ASD **100**.

For example, either the wire I/O interface **311** and/or the components of the ASD **100** may measure the voltage, current, impedance, resistance or any other electrical characteristic associated with the wire **102**. For example, either the wire I/O interface **311** or the components of the ASD **100** may measure the current present on any of the conductors of a wire **102** with any number of suitable current measuring devices, such as a current transformer. As another example, the wire I/O interface **311** or the components of the ASD **100** may measure the voltages present on any of the conductors of a wire **102** with any number of suitable voltage measuring devices, such as a signal conditioning circuit or a volt meter. Each component of the ASD **100** may include measurement devices associated with that component or, alternatively, one component of the ASD **100** may make use of a measurement device used by another component of the ASD **100**. As desired in certain embodiments, the ASD **100** may include a single set of measurement devices in the wire I/O interface **311** that are used by all of the components of the ASD **100**, as shown in FIG. **3**. Additionally, the wire I/O interface **311** may be adapted to the type of wire **102** that is connected on the load side of the ASD **100**, such as flat wire **105** or conventional wire **107**. Alternatively, the wire I/O interface **311** may facilitate the taking of electrical measurements from a wide variety of different types of wiring that may be connected to the ASD **100**.

Additionally, the wire I/O interface **311** or the components of the ASD **100** may include excitation circuitry or devices that are capable of communicating a signal onto one or more of the conductors of the wire **102**. Excitation circuits or devices may be capable of communicating a current signal onto one or more of the conductors of the wire **102**. For example, excitation circuits or devices may be capable of communicating a current signal onto one or more conductors or layers of a flat wire, such as flat wire **105** or onto one or more conductors of a conventional wire, such as wire **107**. Suitable excitation circuits or devices for communicating a current signal onto one or more of the conductors of the wire **102** include, but are not limited to, current transformers, current sources, isolators, multiplexers, and relays. As an alternative to, or in addition to transmitting a current signal onto the wire **102**, excitation circuits or devices may be capable of transmitting a voltage signal onto one or more conductors of the wire **102**. For example, excitation circuits or devices may be capable of communicating a voltage signal onto one or more conductors or layers of a flat wire, such as flat wire **105** or onto one or more conductors of a conventional wire, such as wire **107**. Suitable excitation circuits or devices for transmitting a voltage signal onto one or more conductors of the wire **102** include, but are not limited to, voltage transformers, multiplexers, drivers, and voltage sources. Each component of the ASD **100** may include excitation circuit devices associated with that component or, alternatively, one component of the ASD **100** may make use of an excitation device used by another component of the ASD **100**. The ASD **100** may also include a single set of excitation circuits or devices in the wire I/O interface **311** that are used by all of the components of the ASD **100**, as shown in FIG. **3**. As explained in greater detail below, the excitation devices may be used in conjunction with the measurement devices to perform tests on the wire **102**.

The reactive and proactive safety components of the ASD **100** may operate independently of one another, or, alternatively, their operation may be controlled by the control unit **312**. In the illustrative embodiment of FIG. **3** with a single set of measurement devices contained within a wire I/O interface **311**, the individual safety components may receive electrical measurements from the wire I/O interface **311** or, alternatively, the individual safety components may receive electrical measurements from the wire I/O interface **311** through the control unit **312** or through another safety component. Additionally, one or more of the various safety components of the ASD **100** may share one or more circuit components.

According to an aspect of the invention, a ground fault circuit interrupter (GFCI) safety component **315** may be associated with the ASD **100**, which will be referred to herein as a GFCI component **315**. The GFCI component **315** may detect ground faults in a wire **102** that is monitored. A ground fault is an unintentional electric path which diverts current to ground. The GFCI component **315** may detect ground faults on a variety of different types of wiring that may be connected on the load side of the ASD **100**, such as conventional wiring or flat wiring.

According to certain embodiments of the invention, the GFCI safety component **315** may be specially designed to account for the fact that it is being used in conjunction with flat wire, such as flat wire **105**, as discussed below. As previously mentioned, in connection with FIG. **2**A, a flat wire **105** will typically have one electrifiable or hot conductor **205** and may have one or more return or neutral conductors **210**, **215**. The GFCI component **315** may monitor the current differential between the electrifiable conductor **205** and the one or more return conductors **210**, **215** of the flat wire **105**. If the current flowing through the electrifiable conductor **205** differs from the combined current flowing through any of the one or more return conductors **210**, **215** by more than a predetermined threshold amount, then the GFCI component **315** may cause the ASD **100** to open a relay **310**, thereby preventing the further flow of electrical power onto the flat wire **105**. For example, the GFCI component **315** may cause the ASD **100** to open the relay **310** if the current differential between the electrifiable conductor **205** and the combined current in any of the one or more return conductors **210**, **215** (or H-N) is approximately 5.5 milliamps or greater. The GFCI component **315** may be set to open the relay **310** of the ASD **100** based on any number or measured current differentials.

According to certain embodiments of the invention, the GFCI safety component **315** may be designed to account for the construction of conventional wiring, such as wire **107**, that may be connected on the load side of the ASD **100**. The GFCI component **315** may monitor the current differential between the electrifiable conductor **250** and the return conductor **255** of the conventional wire **107**. If the current flowing through the electrifiable conductor **250** differs from the current flowing through the return conductor **255** by more than a predetermined threshold amount, then the GFCI component **315** may cause the ASD **100** to open a relay **310**.

Additionally, the trip time of the GFCI component **315**, or the time it takes the GFCI component **315** to open a relay **310**, may vary with the current differential detected by the GFCI component **315**. For example, a slower trip time may be associated with a smaller current differential, and a faster trip time may be associated with a higher current differential. The trip time of the GFCI component **315** may be a linear function of the current differential detected by the GFCI component **315**. Alternatively, the trip time of the GFCI component **315** may be a non-linear function of the current differential detected by the GFCI component **315**, such as that defined by UL943, a standard established by Underwriters Laboratories, Inc. (UL).

According to another aspect of the invention, an arc mitigation circuit (AMC) safety component and/or arc fault circuit interrupter (AFCI) safety component **320** may be associated with the ASD **100**. As used herein, the term arc mitigation circuit safety component may refer to a safety component that is designed to identify or detect arcing conditions and/or arc faults that are present on a monitored flat wire. As used herein, the term arc fault circuit interrupter safety component may refer to a safety component that is designed to identify arc faults that are present on other types of wiring monitored by the ASD **100**, such as conventional wiring. The AMC safety component and/or the AFCI safety component may include software components, firmware components, special purpose circuits, application specific circuits, and/or other circuitry as desired in various embodiments of the invention.

According to certain embodiments of the invention, an arc mitigation circuit (AMC) safety component **320** may be associated with the ASD **100**, which will be referred to herein as an AMC component **320**. The AMC component **320** may detect an arcing condition that is present on a flat wire, such as flat wire **105**. An arcing condition may include a high power discharge of electrical energy between two or more conductors. The arcing condition does not necessarily need to exceed the normal maximum load limits of a component of the wire system **101**. The normal maximum load limit of a standard electrical outlet, for example, is 120 volts at 15 amps, or 1800 watts. The electrical energy discharged by an arcing condition may or may not exceed 1800 watts. For conventional wiring, there is a wide array of arc fault current signatures, but the signatures are typically characterized by spikes of current near the voltage peaks of an electrical signal as opposed to a sinusoidal signature. Arc faults or arcing faults on conventional wire are one of the major causes of fires attributed to home electrical wiring as normal circuit breakers do not reliably detect and trip on arc faults. When unwanted arcing occurs, it may generate high localized or spot temperatures that can ignite nearby combustibles such as wood, paper and carpets.

An arcing condition on a flat wire **105** may be very different than an arcing condition on a conventional wire. An arcing condition on a flat wire **105** may be, under certain conditions, a short duration flash which may be referred to as an arc flash. Other types of arc faults and/or arcing conditions may also be present on a flat wire **105**, and the ASD **100** may monitor the flat wire **105** for these other types of arc faults and/or arcing conditions. A typical flash, if not eliminated, may last from the time that electrification of the flat wire **105** is initiated until the time that a wire fault is identified and the relay **310** is opened. The over-current protection component **325** and the ground current monitoring component **330** may be the primary safety components that are responsible for removing power to the flat wire **105** due to a penetration or other type of wire fault resulting in abnormally high RMS currents. In the case of arcing events that result from ohmic or higher resistance "shorts," there may be an associated arc signature current that has a high peak-to-peak value, but an RMS value that does not exceed the standard current limit of 15 amps RMS. Because standard arc faults are relatively slow phenomena, requiring several alternating current cycles to detect and respond to, they are different than the arc flashes that may occur on a flat wire **105**. The AMC component **320**, AFCI component, and/or the other safety components of the ASD **100** may be designed to work in combination or as a system to mitigate arc flash and/or arc fault events identified on a monitored wire **102**.

There are typically two types of arc flash and/or arc fault events that may occur on a monitored wire **102**. The first type is possible during a live (electrified) penetration of the wire **102** by a penetrating object whereby, under certain circumstances, a blow-by or escape of hot gases or particulate matter may occur around the perimeter of the penetrating object. The second type of arc flash or arc fault event is possible after a penetrating object has been removed from the wire **102**. If the wire **102** is electrified again, an arc flash or arc fault may occur prior to other safety components of the ASD **100** identifying a wire fault. From the time that the wire **102** is electrified until the ASD **100** or other safety device reacts to de-energize the wire **102** once again, an arc flash or arc fault is possible whereby hot gases and particulate matter are expelled from the orifice left by the removed object.

The AMC or AFCI component **320** may be designed to reduce the amount of energy and temperature of the expelled gases and particulate matter in the aforementioned types of arc flash and/or arc fault events. For example, a current level and/or signature analysis may be monitored during the arc flash or arc fault events. In certain embodiments, such as embodiments using flat wire **105**, the construction and materials used in the flat wire **105** itself may also have mitigating effect on arc flash events. The flat wire **105** may contains individual layers of insulated conductors which can be further bonded to form an essentially inseparable set of strata. This bonding technique tends to mitigate the arc flash events by enforcing lower impedance interlayer shorts. Accordingly, the safety components of the ASD **100** may be capable of more easily detecting these events. Additionally, the load side wire integrity component discussed below with reference to FIG. **12** may allow potential arcing conditions to be more easily recognized.

For arc current level and/or signature detection of an arc flash or fault, the AMC or AFCI component **320** may be operable to sense the current waveform on the electrifiable conductor **205** or **250** via a suitable current detection device, for example, a current transformer. The AMC or AFCI component **320** may analyze the rate of change of the current, the peak current, the current level, and/or the phasing of the peak current in order to make a decision on the presence of an arcing event.

As with the GFCI component **315**, the AMC component **320** may be designed to take the physical characteristics of flat wire **105** into account, as discussed below. The AMC component **320** may detect specific arcing conditions which may occur on the flat wire **105** that may be hazardous. The AMC component **320** may discriminate between unwanted arcing conditions and normal arcing conditions. A normal arcing condition may be the switching on or off of a circuit or unplugging a device from an electrical outlet. An unwanted arcing condition may be present on the flat wire **105** if there is a penetration, puncture, or flaw in the insulation layers **230** between the electrifiable conductor **205** and one of the other conductors of the flat wire **105**. If multiple layers of insulation are present between two conductors of the flat wire **105**, such as to envelope each conductor separately, an arc flash may occur if each layer of insulation has a flaw (e.g., hole) and the flaws are situated in close proximity to one another. In other words, an arc flash may occur if the insulation layer flaws line up with one another or are in close proximity to one another. An arc flash condition may also occur if the flat wire **105** is penetrated by a foreign object and the penetrating object is removed from the flat wire **105**. A situation might exist in which the conductors are no longer shorted together once the foreign object has been removed, and an arc flash might occur if the flat wire **105** is electrified.

The AMC component **320** uses current sensing circuitry to discriminate between normal and unwanted arcing conditions within the flat wire **105**. The AMC component **320** may detect specific arc flash current signatures which are unique to flat wire **105**. These flat wire **105** arc flash current signatures are often different than the arc fault current signatures of conventional wire. Additionally, the AMC component **320** may be configured to detect arcing conditions originating at a point in a wire that is beyond the flat wire **105** termination at the destination module **120**, including arc flashes in another flat wire **105** or arc faults in a conventional wire that is external to the flat electrical wire system **101**. Once an unwanted arcing condition is detected in the flat wire **105** or any down-line load, a relay **310** is opened to de-energize the flat wire **105**, thus reducing the potential of a fire or other hazardous situation occurring.

A flat wire **105** arc flash signature may differ from the arc fault signature of other forms of electrical wire due to the physical construction of the flat wire **105** that includes stacked conductive layers in close proximity to one another. Once an arc flash condition begins in the flat wire **105**, typically at the initial point of penetration or damage to the flat wire **105**, high temperature droplets of copper and carbonized debris may be ejected away from the penetration sight. Although most of the copper and debris are ejected out of the damaged site orifice of the flat wire **105**, some may proceed transversely into the flat wire **105**, thus increasing the radius of the damaged area. If this phenomena proceeds unchecked, it may build or avalanche into larger areas with unique current signatures specific to the flat wire **105**.

A potentially dangerous situation that may lead to an arc flash on the flat wire **105**, for example, a wire fault on the flat wire **105**, may be detected by one or more of the other safety components of the ASD **100**, as explained in greater detail below. Accordingly, potentially dangerous situations that may lead to an arc flash may be detected prior to the formation of an arc flash on the flat wire **105**.

According to certain embodiments of the invention, an arc fault circuit interrupter (AFCI) safety component **320** may be associated with the ASD **100**, which will be referred to herein as an AFCI component **320**. An AFCI component **320** may detect arc faults on wiring, such as conventional wire **107**, that is connected on the load side of the ASD **100**. The AFCI component **320** may detect the current and voltage characteristics of arcing faults on conventional wire **107** and may open the relay **310** if an arc fault is detected. A wide array of different arc fault current signatures may be detected in accordance with embodiments of the invention utilized to monitor conventional wire. These arc faults may typically be characterized by spikes of current near the voltage peaks of an electrical signal as opposed to a sinusoidal signature.

According to another aspect of the invention, an over-current protection safety component **325** may be associated with the ASD **100**, which will be referred to herein as an over-current protection component **325**. The over-current protection component **325** may provide primary and/or secondary over-current protection. If too much current is allowed to flow through a wire, such as wire **102**, the wire may overheat and there is a potential that a fire could be started in nearby combustibles such as wood, paper and carpets. The over-current protection component **325** may provide secondary over-current protection in addition to that provided by a standard circuit breaker. Typically, circuit breakers are rated with a maximum current that they can effectively handle in order to trip properly, and a circuit breaker may be ineffective if the current flowing through a circuit (which may be created by a short) is higher than the maximum rated current of the circuit breaker. If such a situation arises, the over-current protection component **325** of the ASD **100** may provide secondary over-current protection. Alternatively, the over-current protection component **325** may provide primary over-current protection if there is no circuit breaker connected to or associated with the line side power supply **115** or if a connected circuit breaker is ineffective. For example, the over-current protection component **325** would provide primary over-current protection if a homeowner closed a circuit in the circuit breaker by placing a penny across the circuit.

The over-current protection component **325** of the ASD **100** may monitor the current flowing through the electrifiable conductor of a monitored wire **102**, such as electrifiable conductor **205** of a flat wire **105** or electrifiable conductor **250** of a conventional wire **107**. If the current flowing through the electrifiable conductor, such as **205** or **250**, increases above a maximum threshold value, the relay **310** may be opened to de-energize the wire **102**. As desired, the maximum threshold current value may be set at many different values. For instance, the over-current protection component **325** may cause the relay **310** to open if the current in the electrifiable conductor, such as **205** or **250**, exceeds approximately 15 amps (for 120 VAC applications). An over-current protection component **325** may also examine the current flowing through any of the one or more return conductors of a monitored wire **102**, such as return conductors **210**, **215** of an electrical flat wire **105** or return conductor **255** of a conventional wire, in a similar manner to the way in which the electrifiable conductor, such as **205** or **250**, is monitored.

The over-current protection component **325** may utilize a variable scale algorithm in its monitoring of the current in the electrifiable conductor, such as **205** or **250**. Based on the level or amount of over-current present on the electrifiable conductor, such as **205** or **250**, the over-current protection component **325** may have a variable trip time, or time it takes to de-actuate or open the relay **310**. For example, if the maximum allowable current on the electrifiable conductor, such as **205** or **250**, is set at 15 amps and the over-current protection component **325** measures a current of approximately 15.1 amps on the electrifiable conductor **205**, then the trip time of the over-current protection component **325** may be approximately one second. The trip time may or may not be adjusted for the next zero crossing condition. Alternatively, if a current of approximately 50 amps or more is detected on the electrifiable conductor, such as **205** or **250**, then the trip time of the over-current protection component **325** may be approximately an immediate trip time (no added delay) or set for the next zero crossing condition. Having a longer trip time at lower over-current levels may serve to mitigate false tripping situations due to load inrush currents on the wire **102**. Many different smart algorithms with a wide array of trip times may be utilized as desired in conjunction with the over-current protection component **325** of certain embodiments of the invention. Additionally, the trip time of the over-current protection component **325** may be a linear function of the amount of over-current detected by the over-current protection component **325**. Alternatively, the trip time of the over-current protection component **325** may be a non-linear function of the amount of over-current detected by the over-current protection component **325**.

According to yet another aspect of the invention, the ASD **100** may include a ground current monitoring safety component **330** to perform ground current monitoring, which will be referred to herein as a ground current monitoring component **330**. The ground current monitoring component may be utilized as either a reactive component or in conjunction with the proactive components of the ASD **100**. In the flat wire design utilized herein for purposes of disclosing certain embodiments of the invention, there should not be any significant current on a grounding conductor **220**, **225** of any flat wire **105** connected to the ASD **100**. If a significant current is present on a grounding conductor **220**, **225** of the flat wire **105** connected to the ASD **100**, a hazardous condition may exist. For example, there may be a short in the flat wire **105**. Alternatively, a situation might exist in which electrical power is being supplied to a load and some of that electrical power is backfeeding across the flat wire **105** through, for example, one of the grounding conductors **220**, **225**, to the source module **110**. Such a situation might arise if a faulty or malfunctioning appliance is being supplied power by the flat wire **105** or if an external source of power is miswired into the wire system **101** via the load side **125**. In a similar manner, there should not be any significant current on a grounding conductor **260** of a conventional wire **107** connected to the ASD **100**.

The ground current monitoring component **330** monitors the current flowing through one or more of the grounding conductors **220**, **225** of a flat wire **105** connected to the ASD **100** and/or through the one or more grounding conductors of other types of wiring that may be connected to the ASD **100**, such as the grounding conductor **260** of a conventional wire. If the current increases above a predetermined maximum threshold value, then the relay **310** may be opened to de-energize the flat wire **105**. As desired, the maximum threshold current value may be set at many different values. For instance, the ground current monitoring component **330** may open the relay **310** if the current in any of the ground conductors exceeds approximately 3.0 milliamps.

According to an aspect of the invention, the ASD **100** may include a line side wire integrity (or miswire) safety component **335**, also referred to herein as a Source Wire Integrity (SWI) component **335**. The SWI component **335** may be a proactive safety device capable of detecting line side faults or defects in a wire system **101** prior to the full power electrification of the wire **102**. Before the relay **310** of the ASD **100** is closed, thereby allowing the wire **102** to be electrified, the SWI component **335** may test the wire system **101** on the line side and determine whether the line side power source **115** has been properly terminated on the line side. For purposes of this disclosure, the term line side may refer to a power line that is input into the ASD **100**. The line side may be a conventional wire, a flat wire, an electrical outlet, or another input to the ASD **100**.

The SWI component **335** may detect line side miswiring of the line side power source **115**, which may be conventional wiring or flat wire, via the line side input **305**. The line side power source **115** may also be an electrical outlet that the ASD **100** is connected to or plugged into. It is a common mistake for an electrical outlet to be miswired, even by an experienced electrician. A line side miswire may include an open conductor of the line side power source **115**, which may occur when a conductor of the line side power source **115** is not connected to the line side input **305** of the ASD **100**. Alternatively, a line side miswire may occur when one or more conductors of the line side power source **115** are improperly connected to the line side input **305** of the ASD **100**, such as when two conductors are reversed in their connection to the line side input **305**. For example, if the line side power source **115** is a conventional electric wire, the SWI component **335** may detect a situation in which the line side electrifiable or hot conductor and the line side return or neutral conductor have been switched when connected to the line side input **305**. As another example, if the line side power source **115** is an electrical flat wire **105**, the SWI component **335** may detect a situation in which the line side electrifiable conductor **205** and one of the line side return conductors **210** have been switched when connected to the line side input **305**.

The SWI component **335** may contain line side miswire detection circuitry that uses one or more test signals to locate and detect miswire conditions. FIG. **5** is a schematic diagram of on example of a line side wire integrity component **335** that may be incorporated into an ASD **100** according to the invention. A line side power source **115** connected to the line side input **305** of the ASD **100** may include an electrifiable (or hot) conductor **505**, a return (or neutral) conductor **510**, and a grounding conductor **515**. In certain embodiments, the line side input **305** may include more than three conductors. For example, if the line side input **305** is an electrical flat wire similar to the flat wire **105** illustrated in FIG. **2**A, then the line side input **305** may include five conductors.

The SWI component **335** may include three current sensors **520**, **525**, **530** and a signal conditioning circuit **535**. Any number of current sensors and/or signal conditioning circuits may be associated with the SWI component **335**. The SWI component **335** may optionally include an SWI relay driver **540** and an SWI relay **545**. The signal conditioning circuit **535** of the SWI component **335** may be in communication with the control unit **312** of the ASD **100** via a control unit communications link **550** or, alternatively, the signal conditioning circuit **535** may be incorporated into the control unit **312**. The signal conditioning circuit **535**, either on its own or in combination with the control unit **312**, may allow a small test current to be transmitted from the line side power source **115** in order to determine whether any line side miswires are present.

The signal conditioning circuit **535** may be any appropriate signal conditioning circuit, and the signal conditioning circuit **535** may include any number of circuit components. The signal conditioning circuit **535** may operate to limit the value of the currents that are detected on the line side prior to communicating those values to the control unit **312** for analysis. Accordingly, the control unit **312** may receive a current measurement from each of the current sensors **520**, **525**, **530**, and the control unit **312** may utilize these measurements to determine whether the line side is wired correctly. The signal conditioning circuit **535** may locate the electrifiable or hot conductor **505** of the line side power source **115**, regardless of where it is connected to the line side input **305**, and leak a small test current out of the electrifiable conductor **505**. The test signal may be a voltage or current test signal, for example, a current test signal that is under approximately one milliamp. If there is no electrifiable conductor **505** connected to the line side input **305**, then the SWI component **335** will be unable to locate the electrifiable conductor **505** to obtain a test signal. In such a situation, the signal conditioning circuit **535** of the SWI component **335** and/or the control unit **312** may determine that the electrifiable conductor **505** is open on the line side. If, however, an electrifiable conductor **505** is connected to the line side input **305**, the signal conditioning circuit **535** may permit the test signal to leak out of the electrifiable conductor **505**. The signal conditioning circuit **535** may then monitor the currents detected by the current sensors **520**, **525**, **530** to determine whether or not any line side miswires are present. A hot-neutral ("H-N") current sensor **520** may be used to detect a current between the electrifiable (or hot) conductor **505** and the return (or neutral) conductor **510**. A hot-ground ("H-G") current sensor **525** may be used to detect a current between the electrifiable conductor **505** and the grounding conductor **515**. A neutral-ground ("N-G") current sensor **520** may be used to detect a current between the return conductor **510** and the grounding conductor **515**. In certain embodiments, a test current applied to a line side conductor may be limited by appropriate electrical standards and codes. For example, a test current applied to a grounding conductor of a line side power source **115** may be limited to an upper bound of approximately 0.5 milliamps by standards established by Underwriters Laboratory, Inc.

If the line side is wired correctly, a current between the electrifiable conductor **505** and the return conductor **510** will be detected by the H-N current sensor **520**, a current between the electrifiable conductor **505** and the grounding conductor **515** will be detected by the H-G current sensor **525**, and no current between the return conductor **510** and the grounding conductor **515** will be detected by the N-G current sensor **530**. If there is a line side miswire, a different set of current measurements than those discussed above for a properly wired line side may be made by the current sensors **520**, **525**, **530**, and the SWI component **335** may detect the miswire. In addition to an open electrifiable conductor **505**, The SWI component **335** may detect other open conductors on the line side. For example, if the return conductor **510** is open on the line side, no current will be detected between the electrifiable conductor **505** and the return conductor **510** by the H-N current sensor **525**. As another example, if the ground conductor **515** is open on the line side, no current will be detected between the electrifiable conductor **505** and the grounding conductor **515** by the H-G current sensor **525**.

The SWI component **335** may also detect conductors that have been miswired or switched when connected to the line side input **305**. For example, if the electrifiable conductor **505** and the return conductor **510** have been switched when connected to the line side input **305**, the current detected by the H-N current sensor **520** will be reversed because the current will be flowing across the H-N current sensor **520** from the opposite direction. Additionally, no current will be detected by the H-G current sensor **525** and a current will be detected by the N-G current sensor **530**. If the electrifiable conductor **505** and the grounding conductor **515** have been switched when connected to the line side input **305**, the current detected by the H-G current sensor **525** will be reversed because the current will be flowing across the H-G current sensor **525** from the opposite direction. Additionally, no current will be detected by the H-N current sensor **520** and a current will be detected by the N-G current sensor **530**. Any other miswire on the line side that produces a different set of currents across the current sensors **520**, **525**, **535** other than the set of currents representative of a properly wired line side may also be detected by the SWI component **335**.

If the SWI component **335** detects a miswire on the line side, then the relay **310** of the ASD **100** may be maintained in its open position to prevent electrification of the wire **102**. If no miswire is detected by the SWI component **335**, then the relay **310** may be closed, to allow electrification of the wire **102**. Alternatively, if the SWI component **335** detects a miswire on the line side, then the SWI relay **545** may be maintained in its open position to prevent the flow of electrical power from the line side input **305** to the source module **110** via a source module communications link **555**. The source module communications link **555** may be any appropriate communication link, for example, a wired connection. If no miswire is detected by the SWI component **335**, then the SWI relay driver **540** may be used to close the SWI relay **545** and allow electrical power to flow from the line side input **305** to the source module **110**. The SWI component **335** may perform tests on the line side of the wire system **101** during a short time interval after power is applied to the line side power source **115**. For example, the SWI component **335** may perform the tests on the line side of the wire system **101** in no more than approximately 500 milliseconds from the point in time at which power is applied to the line side power source **115**. Additionally, a SWI component flag or state may be set in the ASD **100** to indicate that no miswires were detected by the SWI component **335**. The SWI component flag may be, for example, stored in the memory **405** of the control unit **312** and/or in one or more other memories associated with the control unit **312** and/or the SWI component **335**. The SWI component flag or state may be used by the ASD **100** in conjunction with the results of other tests performed by the ASD **100** in order to determine whether or not the relay **310** of the ASD **100** may be closed. Other data associated with the SWI component **335** and/or the measurements taken in accordance with the operation of the SWI component **335** may be stored in one or more appropriate memory devices, for example, the memory **405** of the control unit **312**.

Although the SWI component **335** is described above as leaking a current signal from the electrifiable conductor **505** of the line side power source **115** and then testing the line side for current signals, as desired in various embodiments, other types of signals, such as a voltage signal may be leaked from the line side power source **115**. Additionally, if a voltage signal is leaked from the line side power source **115**, then the SWI component **335** may detect voltage signals on the line side in order to identify or locate line side miswires.

With continued reference to FIG. **5**, the SWI component **335** may include at least one fuse **560** that is operable to act as a fail safe if too much current flows into the ASD **100** from the line side power source **115**. Although the fuse **560** is illustrated in FIG. **5** as being a part of the SWI component **335**, a fuse may alternatively or additionally be included in other components of the ASD **100**. Additionally, as desired, many different types of fuses may be utilized by the ASD **100**, for example, a standard 50 amp fuse. If a 50 amp fuse is utilized, the fuse **560** may be blown if a current of approximately 50 amps or more flows into the ASD **100** from the line side power source **115**. Once the fuse **560** has been blown, an electrical power signal may no longer be permitted to flow into the ASD **100** from the line side power source **115**.

FIG. **6** is a flowchart of one example of the operation of the SWI component **335**, according to an illustrative embodiment of one aspect of the invention. If power is applied to the SWI component **335** at block **605**, then the SWI component **335** may check a line side power source **115** connected to the line side input **305** for a line side miswire. For example, at block **610**, the SWI component **335** may check the line side power source **115** for an open electrifiable (or hot) conductor **505**. If an open electrifiable conductor **505** is detected, then the SWI component **335** may go to block **640** and prevent the electrification of the flat wire **105** by preventing the relay **310** of the ASD **100** from being closed. If an open line side power source electrifiable conductor **505** is not detected at block **610**, then the SWI component **335** may go to block **615** and check the line side power source **115** for an open return (or neutral) conductor **510**. If an open line side power source return conductor **510** is detected at block **615**, then the SWI component **335** may go to block **640** and prevent the relay **310** of the ASD **100** from being closed. If no open line side power source return conductor **510** is detected at block **615**, then the SWI component **335** may go to block **620** and check the line side power source **115** for an open grounding conductor **515**. If an open line side power source grounding conductor **515** is detected at block **620**, then the SWI component **335** may go to block **640** and prevent the relay **310** of the ASD **100** from being closed. If no open line side power source grounding conductor **515** is detected at block **620**, then the SWI component **335** may go to block **625**. At block **625**, the SWI component **335** may check the line side power source **115** for a reversed electrifiable conductor **505** and return conductor **510**. If the line side power source electrifiable conductor **505** has been reversed with the line side power source return conductor **510** at the line side input **305**, then the SWI component **335** may go to block **640** and prevent the relay **310** of the ASD **100** from being closed. If, however, no reversed line side power source electrifiable conductor **505** and return conductor **510** is detected at block **625**, then the SWI component **335** may go to block **630**. At block **630**, the SWI component **335** may check the line side power source **115** for a reversed electrifiable conductor **505** and grounding conductor **515**. If the electrifiable conductor **505** has been reversed with the grounding conductor **515** at the line side input **305**, then the SWI component **335** may go to block **640** and prevent the relay **310** of the ASD **100** from being closed. If, however, no line side power source reversed electrifiable conductor **505** and grounding conductor **515** is detected at block **630**, then the SWI component **335** may go to block **645** and allow the relay **310** of the SWI component **335** to be closed.

The tests performed by the SWI component **335** do not necessarily have to be performed in the order set forth in the logic of FIG. **5**, but instead may be performed in any suitable order. Additionally, in certain embodiments of the invention, the SWI component **335** does not have to conduct each test set forth in FIG. **5**, but instead may conduct less than all of the tests set forth in FIG. **5**. If any test results in the execution of block **540**, then the SWI component **335** may still perform the remaining tests and may record the outcome of each test, or at least the ones that result in a positive miswire indication. Additionally, if a miswire is detected by the SWI component **335**, an indicator may be stored by the SWI component **335** or by the control unit **312**, and the indicator may include information as to which test(s) resulted in the detection of a miswire. This indicator may also be communicated by the ASD **100** to another device such as a second ASD **100**, a central monitoring device, or a computer. The SWI component **335** and/or the control unit **312** may also be associated with one or more memory devices, for example, the memory **405** of the control unit **312**, that are operable to store a variety of indicators and/or measurements data associated with the operation of the SWI component **335**.

According to another aspect of the invention, the ASD **100** may include a load side or destination integrity (or load side miswire or short/fault detection) component **340**, which will be referred to herein as a destination wire integrity (DWI) component **340**. The DWI component **340** may be a proactive safety device capable of detecting faults or defects in the wire **102** or miswires on the load side prior to the full power electrification of the wire **102**. For purposes of this disclosure, the term load side may be utilized to refer to a wire **102**, such as a flat wire **105**, conventional wire **107**, or other wire connected between the ASD **100** and a downstream destination device **117** and/or a downstream ASD **100**. Before the relay **310** of the ASD **100** is closed, thereby allowing the wire **102** to be electrified, the DWI component **340** may test the wire **102** on the load side and determine whether the wire **102** is free of faults, defects, and/or miswires. The DWI component **340** may test the wire **102** by applying either a voltage or a current test signal to one or more of the conductors of the wire **102** and measuring a response on the other conductors of the wire **102**, as explained in greater detail below. The DWI component **340** may use one or both of a voltage-based test system and a current-based test system to check the wire **102** for miswires and wire faults, as described in greater detail below.

According to one aspect of the invention, the DWI component **340** may detect load side miswiring of the wire **102**. A load side miswire may include an open conductor of the wire **102**, which may occur when a conductor of the wire **102** is not connected to the destination module **120** or the source module **110**. In addition, a load side miswire may include conductors of the wire **102** that are improperly connected to the destination module **120**, for example, two conductors that are reversed in their connection to the destination module **120**. For example, the DWI component **340** may detect a situation in which an electrifiable conductor, such as electrifiable conductor **205** of a flat wire **105**, and one or more return conductors, such as return conductor **210** of a flat wire **105**, have been switched when connected to the destination module **120**. As another example, the DWI component **340** may detect a situation in which the electrifiable conductor **250** of a conventional wire **107** and the return conductor **255** of the conventional wire **107** have been switched when connected to the destination module **120**. The DWI component **340** may detect miswires in both flat wiring and conventional wiring. If the DWI component **340** detects a miswire on the load side, then the relay **310** is maintained in its open position to prevent electrification of the wire **102**.

According to another aspect of the invention, the ASD **100** may detect potentially hazardous conditions that may exist in association with a wire **102**. Potentially hazardous conditions may be detected for many different types of wiring, such as flat wiring, conventional wiring, and/or wiring with concentric conductors. One hazardous situation of particular importance is the penetration of a flat wire, such as flat wire **105**, that can lead to an inter-layer short in the flat wire **105**. An inter-layer short occurs when a conductor in the flat wire **105** is placed in contact with one or more other conductors in the flat wire **105**. Inter-layer shorts typically occur when an object, and particularly a metal object, penetrates the flat wire **105**. Various types of penetrations of the flat wire **105** have been considered and analyzed. With respect to a flat wire **105** installed on a surface such as a wall or ceiling, typical penetration may be caused by nails, screws, push-pins, thumbtacks, staples, knife cuts, or saw cuts. Each type of penetration offers a different challenge to overcome fire and shock hazards. Penetrations may occur while the flat wire **105** is electrified or prior to its electrification. Penetrating objects may or may not be present during the initial electrification of a flat wire **105**. In addition to inter-layer shorts, penetrations of the flat wire may lead to arc flashes or other arcing conditions which may be detected by the AMC safety component of the ASD **100**. Potentially hazardous conditions may also be detected in conventional wire, such as wire **107**. For example, the conventional wire **107** may be penetrated in a similar manner, leading to a short between two or more conductors of the conventional wire **107**.

For flat wire **105**, low impedance inter-layer shorts are typically needed in order to cause a primary safety device such as a circuit breaker to trip. These more desirable low impedance shorts, sometimes referred to as dead or good shorts, typically occur during the penetration of a flat wire **105** or after the penetration of a flat wire **105** when the penetrating object is still embedded in the flat wire **105**. Once the penetrating object is removed from the flat wire **105**, there may no longer be a penetrating metal object to provide a parallel path through which current can flow, thereby removing the good inter-layer short. Additionally, the penetrating object no longer adds a compressive force that serves to press the conductors of the flat wire **105** together. This lack of compressive force may contribute to the failure to maintain a good quality inter-layer short. After the removal of the penetrating object, therefore, the inter-layer shorts are typically not low impedance inter-layer shorts, which makes a successful trip of a primary safety device such as a circuit breaker less likely.

The DWI component **340** of the ASD **100** may aid in the detection of inter-layer shorts and/or other shorts, as explained in greater detail below. The DWI component **340** may be a proactive safety device capable of detecting faults or defects in a flat wire **105** or conventional wire **107** prior to the full power electrification of the flat wire **105** or conventional wire **107**. Alternatively, as explained in greater detail below with reference to FIG. **11**, the DWI component **340** may include a combination of proactive and reactive components. If a proactive device is utilized, then prior to the relay **310** being closed, the DWI component **340** checks for inter-layer shorts in the flat wire **105**, which may have been caused by a penetration of the flat wire **105**. Similarly, the DWI component **340** may check for shorts in a conventional wire **107** which may have been caused by a penetration of the conventional wire **107**. The DWI component **340** may detect both low impedance shorts (e.g., dead or good shorts) and high impedance shorts in a wire **102**. If a short is detected, then the DWI component **340** or the control unit **312** may open the relay **310** and prevent electrification of the wire **102**. In a DWI component **340** that includes both proactive and reactive components, the DWI component **340** may detect shorts and/or wire faults (and miswires) by electrifying one or more conductors of the wire **102** and monitoring one or more of the conductors of the wire **102** for a return signal.

In both a voltage-based and current-based method of testing, the DWI component **340** may apply or communicate a test signal onto one or more conductors or layers of the wire **102** and test for a return signal on one or more of the other conductors or layers of the wire **102**. If a flat wire, such as flat wire **105**, is tested, then the two return conductors **210**, **215** may form a return conductor loop and the two grounding conductors **220**, **225** may form a grounding conductor loop. A loop may occur when a signal travels from the ASD **100** through the flat wire **105** via one conductor, to the destination module **120** and then back via another conductor of the flat wire **105** to the ASD **100**. For example, a signal may travel through the flat wire **105** via a first return conductor **210**, through the destination module **120**, and back through the flat wire **105** via the second return conductor **215**. The DWI component **340** may test the return conductor loop and the grounding conductor loop with independent test signals. Alternatively, the DWI component **340** may test the return conductor loop and the grounding conductor loop with a single test signal. If a single test signal is used to test the return and grounding conductor loops, alternating periods of the test signal may be used to test the return and grounding conductor loops independently. Additionally, if both the return and grounding conductor loops are determined to be properly terminated by the DWI component **340**, the DWI component **340** may presume that the electrifiable conductor **205** of the flat wire **105** is properly terminated at the destination module **120**. Alternatively, the DWI component **340** may perform additional tests on the electrifiable conductor **205** in order to determine whether or not the electrifiable conductor **205** is terminated properly. For example, the DWI component **340** may test the electrifiable conductor **205** to determine whether or not the electrifiable conductor **205** is shorted to one or more of the return conductors **210**, **215** or the grounding conductors **220**, **225**.

FIG. **7** is a flowchart of one example of the general operation of a DWI component **340**, according to an illustrative embodiment of the invention. The methodology of FIG. **7** may be implemented by the DWI component **340** for either a voltage-based test system or a current-based test system. Additionally, the DWI component **340** may be utilized to test many different types of wire, including flat wire, such as flat wire **105**, and conventional wire, such as wire **107**. If power is applied to the DWI component **340** at block **705**, then the DWI component **340** may go to block **710**. At block **710**, the DWI component **340** may test one or more grounding conductors of the wire **102**. For example, the DWI component **340** may test the grounding conductor loop of a flat wire **105**. As another example, the DWI component **340** may test the ground or grounding conductor **260** of a conventional wire **107**. At block **715**, the DWI component **340** may determine whether or not the one or more grounding conductors have been terminated properly and whether or not there is a fault in the grounding conductor of the wire **102**. For a flat wire **105**, the DWI component may determine whether or not the grounding conductor loop has been terminated properly and whether or not there is a fault in the grounding conductors **220**, **225** at block **715**. If the one or more grounding conductors are determined not to be properly terminated or a fault is found in one of the grounding conductors, such as grounding conductors **220** and **225** if a flat wire **105** is tested, then, the DWI component **340** may go to block **740** and prevent the relay **310** from being closed to prevent electrification of the wire **102**. If, however, the one or more grounding conductors (e.g., grounding conductor loop of a flat wire **105**) are determined to be properly terminated and no faults are found in the one or more grounding conductors, such as conductors **220** and **225**, at block **715**, then the DWI component **340** may go to block **720**. At block **720**, the DWI component **340** may test the one or more return conductors of the wire **102**. For example, the DWI component **340** may test the return conductor loop of a flat wire **105** or the DWI component **340** may test the return conductor **255** of a conventional wire **107**. The DWI component **340** may determine whether or not the one or more return conductors have been terminated properly and whether or not there is a fault in the one or more return conductors of the wire **102** at block **725**. If one or more of the return conductor loop are determined not to be properly terminated or a fault is detected in one or more of the return conductors, such as conductors **210**, **215** if a flat wire **105** is tested, then the DWI component **340** may go to block **740** and prevent the relay **310** from being closed to prevent electrification of the wire **102**. If, however, the one or more return conductors (e.g., return conductor loop of a flat wire **105**) are determined to be properly terminated and no wire faults are found in the one or more return conductors at block **725**, then the DWI component **340** may go to block **730**. At block **730**, the DWI component **340** may test the electrifiable conductor of the wire **102**, such as electrifiable conductor **205** if a flat wire **105** is tested or electrifiable conductor **250** if a conventional wire is tested, in order to determine whether or not it is properly terminated and whether or not there are any wire faults in the electrifiable conductor. If, at block **735**, it is determined that the electrifiable conductor (e.g., conductor **205** or **250**) is not properly terminated or that a wire fault is detected on the electrifiable conductor, then the DWI component **340** may go to block **740** and prevent the relay **310** from being closed. If, however, the electrifiable conductor (e.g., conductor **205** or **250**) is determined to be properly terminated and no wire faults are detected on the electrifiable conductor at block **735**, then the DWI component **340** may go to block **745** and allow the relay **310** to be closed. Alternatively, a DWI component flag may be set and stored by the control unit **312**, and the flag may be used by the ASD **100** in conjunction with other tests to determine whether or not the relay **310** may be closed.

The tests performed by the DWI component **340** do not necessarily have to be performed in the order set forth in the logic of FIG. **7**, but instead may be performed in any suitable order. As previously mentioned, some of the tests set forth in FIG. **7** may be performed in parallel with one another. Additionally, the DWI component **340** does not have to conduct each test set forth in FIG. **7**, but instead may conduct less than all of the tests set forth in FIG. **7**. If any test results in the execution of block **740**, then the DWI component **340** may still perform the remaining tests and may record the outcome of each test, or at least the ones that result in a positive miswire indication. Additionally, if a miswire is detected by the DWI component **340**, an indicator may be stored by the DWI component **340** or by the control unit **312**, and the indicator may include information as to which test(s) resulted in the detection of a miswire. This indicator may then be transmitted by the ASD **100** to another device such as a second ASD **100**, a central monitoring device, or a computer. The DWI component **340** and/or the control unit **312** may be associated with one or more memory devices, for example, the memory **405** of the control unit **312**, operable to store a variety of indicators and/or measurements data associated with the operation of the DWI component **340**.

FIG. **8**A is one example of a timing diagram of test signals that may be applied by a DWI component **340**, according to an illustrative embodiment of one aspect of the invention. The timing diagram depicted in FIG. **8**A may be applicable to testing certain types of flat wire, such as flat wire **105**. As mentioned earlier, the return conductor loop and grounding conductor loop may be tested at alternating periods **805** and **810** of the test signal in order to isolate the loop that is being tested. According to an aspect of the invention, the signal used to drive the return and grounding conductor loops may be any signal with an alternating period, such as a 2400 Hertz (Hz) square wave signal. The signal may be generated by a microcontroller, clocking circuit, or other signal generation device and communicated onto the two loops of the flat wire **105**, as explained in greater detail below. For example, the signal may be generated by one or more suitable components of a control unit **312** of the ASD **100**. The signal may be passed through a low pass filter before being communicated onto one or more of the conductors of the flat wire **105** to remove any unwanted noise and/or harmonics. Tests on both the return conductor loop and ground conductor loop may be performed with the same test signal and, if it is determined that both loops are properly terminated and no faults are detected on the flat wire **105**, then the relay **310** of the ASD **100** may be closed in order to allow the flat wire **105** to be electrified. In addition, a flag or state may be set in the ASD **100** to indicate whether the conductor loops are terminated properly. A conductor loops termination flag may be used in conjunction with the results of other tests performed by the ASD **100** in order to determine whether or not the relay **310** of the ASD **100** may be closed. The tests on both loops may be conducted by the DWI component **340** within a first time of approximately 300 milliseconds or less **815** and then the decision of whether or not to close the relay **310** may be made by a second time **820**. The second time **820** may be less than approximately 375 milliseconds. The timing set forth in FIG. **8**A is one example of timing and that a variety of timing goals or benchmarks may be utilized in accordance with embodiments of the invention.

FIG. **8**B is another example of a timing diagram of test signals that may be applied by a DWI component **340**, according to an illustrative embodiment of one aspect of the invention. The timing diagram depicted in FIG. **8**B may be applicable to testing various types of wire, such as conventional wire **107**. With reference to the conventional wire **107** depicted in FIG. **2**B, the return conductor **255** and grounding conductor **260** may be tested at alternating periods **825** and **830** of the test signal in order to isolate the conductor that is being tested. Additionally, in certain embodiments of the invention, the electrifiable conductor **250** may be tested. According to an aspect of the invention, the signal used to drive the respective tests of the return and grounding conductor may be any signal with an alternating period, such as, a 2400 Hertz (Hz) square wave signal. The signal may be generated by a microcontroller, clocking circuit, or other signal generation device and communicated onto the two conductors of the wire **107**. For example, the signal may be generated by one or more suitable components of a control unit **312** of the ASD **100**. The signal may be passed through a low pass filter before being communicated onto one or more of the conductors of the wire **107** to remove any unwanted noise and/or harmonics. Tests on both the return conductor **255** and ground conductor **260** may be performed with the same test signal and, if it is determined that both conductors are properly terminated and no faults are detected on the wire **107**, then the relay **310** of the ASD **100** may be closed in order to allow the wire **107** to be electrified. In addition, a flag or state may be set in the ASD **100** to indicate whether the conductors are terminated properly. A conductor termination flag may be used in conjunction with the results of other tests performed by the ASD **100** in order to determine whether or not the relay **310** of the ASD **100** may be closed. The tests on both conductors may be carried out by the DWI component **340** within a first time **815**, such as approximately 300 milliseconds or less, and then the decision of whether or not to close the relay **310** may be made by a second time **820**. The second time **820** may be less than approximately 375 milliseconds. The timing set forth in FIG. **8**B is merely one example of timing and that a variety of timing goals or benchmarks may be utilized in accordance with various embodiments of the invention.

According to some embodiments of the invention, the wire **102** may be tested by the DWI component **340** by electrifying one or more conductors of the wire **102** and testing one or more of the conductors of the wire **102** for a return signal. This manner of testing may be particularly applicable to electrical flat wire **105** in order to test for interlayer shorts due to the stacked arrangement of the electrical flat wire **105**. For example, as explained in greater detail below with reference to FIG. **11**, one or more of the return conductors **210**, **215** of an electrical flat wire **105** may be electrified and one or more of the conductors of the flat wire **105** may be monitored or tested for a return signal. Miswires and/or wire faults may be identified based at least in part on one or more return signals. A similar method may be conducted by electrifying one or more of the grounding conductors **220**, **225** and testing one or more of the conductors of the flat wire **105** for a return signal. The one or more conductors that are electrified for testing may be electrified for any period of time in order to conduct the testing.

As desired, the electrifiable conductor **205**, **250** of a monitored wire **102** may be electrified for a predetermined period of time, and one or more conductors of the wire **102** may be monitored for miswire and/or wire faults. For example, the relay **310** may be closed at one zero crossing and then opened at the next zero crossing, thereby permitting one half cycle of an electrical power signal from the line side power source **115** to be communicated onto the wire **102**. One or more conductors of the wire **102** may then be monitored for return signals that indicate the presence of miswires and/or wire faults. For example, if a return signal is detected on one or more of the grounding conductors **220**, **225** or a flat wire **105** or the grounding conductor **260** of a conventional wire **107**, a miswire or short may be present on the monitored wire **102**. If a miswire or short is identified, then the DWI component **340** and/or the control unit **312** may prevent the further electrification of the wire **102** by maintaining the relay **310** in its opened position. The testing described above may be conducted at any time by the DWI component **340**, for example, during the initial electrification of the wire **102** following installation or a reset condition of the ASD **100**. The predetermined period of time that the wire **102** is electrified for testing may be virtually any predetermined period of time as desired. A half cycle of an electrical power signal is merely discussed as one example of a period of time.

A conventional wire, such as wire **107**, or other types of wiring may be tested in a similar manner as an electrical flat wire **105**. For example, a test signal may be applied to one conductor of a conventional wire **107** and the other conductors of the conventional wire **107** may be tested for a return signal. The tests that may be performed by a DWI component **340** that are described below are described with reference to an electrical flat wire **105**; however, similar tests may be adapted to and applied to other types of wiring, such as to a conventional wire **107**.

Additionally, the tests performed by the DWI component **340** may be contained between the source module **110** and the destination module **120** of the wire system **101**. Accordingly, a current or voltage is not allowed to pass either to the line side source **115** or to the load side destination **125**.

The DWI component **340** may use a voltage-based method to test a wire **102** for miswires and wire faults on the load side. The voltage-based method directly applies a voltage test signal to selected conductors or layers (stimulated layers) of the wire **102** while measuring voltages on the remaining conductors or layers (non-stimulated layers). Wire faults, or unwanted conductance between the conductors in the form of low or high impedance shorts, may be identified by detecting unexpected voltage present on the non-stimulated conductors or layers.

FIG. **9**A is a schematic diagram of a voltage-based DWI component **340** that may be incorporated into an ASD **100** according to one aspect of the invention. As a preliminary matter, it may be noted that FIG. **9**A depicts a different source device **103** than that shown in FIG. **3**. In FIG. **9**A, the line side power source **115** is incorporated into the source device **103**. Such a situation might occur, for example, if the source device **103** includes a standard electrical plug that may be plugged into an electrical outlet.

As shown in FIG. **9**A, The voltage-based DWI component **340** may include a source/sense circuit **900**, an electrifiable (or hot) conductor connection **901**, a return conductor connection **902**, a grounding conductor connection **903**, and one or more test signal relays **904**. The source/sense circuit **900** may be configured to transmit a voltage test signal onto one of the conductors of the flat wire **105** and then monitor the conductors of the flat wire **105** for a return voltage. As desired in various embodiments, the source/sense circuit **900** may test more than one conductor of the flat wire **105** simultaneously be using alternating periods of the same test signal, as explained in greater detail above with reference to FIG. **8**. The source/sense circuit **900** may transmit a voltage test signal onto the electrifiable conductor **205** and/or monitor the electrifiable conductor **205** via the electrifiable conductor connection **901**. Similarly, the source/sense circuit **900** may transmit a voltage test signal onto one or more of the return conductors **210**, **215** and/or monitor one or more of the return conductors **210**, **215** via the return conductor connection **902**. Additionally, the source/sense circuit **900** may transmit a voltage test signal onto one or more of the grounding conductors **220**, **225** and/or monitor one or more of the return conductors **220**, **225** via the grounding conductor connection **902**.

The voltage-based test signal transmitted by the source/sense circuit **900** may be a low voltage signal. The voltage-based test signal may be, for example, at a voltage of approximately 5 volts or at a voltage of approximately 12 volts, although other voltage levels may be used as desired for the test signal. As a safety precaution, the maximum amplitude of the voltage-based test signal may be limited to approximately 30 volts, although a test signal with an amplitude of greater than approximately 30 volts may be used in conjunction with certain embodiments of the invention. Additionally, the voltage-based test signal may be derived from the signal coming into the ASD **100** from the line side power source **115**. The source/sense circuit **900** may receive a voltage signal from the line side power source **115** and step that signal down to a low voltage signal that may be used or modified to perform tests on the flat wire **105**. For example, the source/sense circuit **900** may receive a voltage signal of approximately 110-130 V or approximately 220-250 V and step that voltage signal down to a low voltage signal for testing the flat wire **105**. The voltage may be stepped down using a step down transformer, capacitor, or any other suitable device for decreasing the amplitude of a voltage signal. Additionally, the source/sense circuit **900** may constitute an isolated power source when applying a test signal to the flat wire **105**.

A voltage test relay **904** may be used by the DWI component **340** to ensure that the flat wire cannot be fully electrified while it is being tested by the DWI component **340**. As shown in FIG. **9**A, the voltage test relay **904** may be a double-pole single throw relay, although other types of relays or combinations of relays may be used in accordance with embodiments of the invention. If the voltage test relay **904** is in a closed position, then electrical power may be allowed to flow from the line side power source **115** through the ASD **100** and onto the flat wire **105**. If, however, the voltage test relay **904** is in a test position (or opened position), then electrical power will not be permitted to flow from the line side power source **115** through the ASD **100** and onto the flat wire **105**. Instead, the voltage-based test signal will be allowed to flow from the source/sense circuit **900** onto the flat wire **105**. In certain embodiments, the voltage test relay **904** may be the same circuit as that used for the main or common relay **310**, as shown in FIG. **9**A. Alternatively, the voltage test relay **904** may be one or more separate relays used in conjunction with the DWI component **340**.

When the voltage test relay **904** is maintained in a test position, the source/sense circuit **900** may transmit or communicate a voltage-based test signal onto one or more of the conductors of the flat wire **105** while monitoring the conductors of the flat wire **105** for a return voltage. For example, the source/sense circuit **900** may communicate a voltage-based test signal onto the electrifiable conductor **205** of the flat wire **105** via the electrifiable conductor connection **901**. The source/sense circuit **900** may then monitor the conductors of the flat wire **105** for a voltage signal to determine whether there are any inter-layer or termination shorts or faults present on the flat wire **105**. If a voltage signal is detected by either the return conductor connection **902** or the grounding conductor connection **903**, the source/sense circuit **900** (or the control unit **312** in communication with the source/sense circuit **900**) may determine that an inter-layer or termination short is present on the flat wire **105** between the electrifiable conductor **205** and one of the other conductors of the flat wire **105**. Similarly, the source/sense circuit **900** may communicate a voltage-based test signal onto the return conductors **210**, **215** of the flat wire **105** via the return conductor connection **902** and then monitor the conductors of the flat wire **105** for a voltage signal to determine whether there are any inter-layer or termination shorts between one or more of the return conductors **210**, **215** and one or more of the other conductors of the flat wire **105**. If a voltage signal is detected by either the electrifiable conductor connection **901** or the grounding conductor connection **903**, it may be determined that an inter-layer or termination short is present on the flat wire **105**. The same method may be used to test the grounding conductors **220**, **225** of the flat wire **105**. The source/sense circuit **900** may communicate a voltage-based test signal onto the grounding conductors **220**, **225** of the flat wire **105** via the grounding conductor connection **903** and then monitor the conductors of the flat wire **105** for a voltage signal to determine whether there are any inter-layer or termination shorts between one or more of the grounding conductors **220**, **225** and one or more of the other conductors of the flat wire **105**. If a voltage signal is detected by either the electrifiable conductor connection **901** or the return conductor connection **902**, it may be determined that an inter-layer or termination short is present on the flat wire **105**.

As shown in FIG. **9**A, a test signal may be applied to either both return conductors **210**, **215** or both grounding conductors **220**, **225** at the same time by the source/sense circuit **900**. However, as desired, a test signal may be individually applied to a single conductor of the flat wire **105**. For example, two return conductor connections may be included to individually apply a test signal to and monitor each of the return conductors **210**, **225** of the flat wire. When determining whether or not inter-layer shorts are present on the flat wire **105**, it is not necessary to individually test and monitor each of the return conductors **210**, **215** or each of the grounding conductors **220**, **225** of the flat wire because a voltage-based test signal applied to one conductor in a loop will be transmitted through the destination module **120** and back to the DWI component **340** in the source device **103** via the associated other conductor in the loop. On the load side, the return signal may be transmitted through only the destination module **120** or, alternatively, the return signal may be transmitted through both the destination module **120** and any load side destination **125** connected to the wire system **101**.

Limits may be placed on the detectable inter-layer impedance range between two conductors of the flat wire **105**. The detectable inter-layer impedance range between the return conductors **210**, **215** and electrifiable conductor **205** may be limited by the possible presence of real loads connected on the load side **125** of the flat wire **105**. An example of such a load would be a hair dryer plugged into an electrical outlet. Real loads connected on the load side **125** may create an impedance on the flat wire **105** as low as 8-10 ohms; therefore, an inter-layer impedance check between the electrifiable **205** and return conductors **210**, **215** may be limited at lower than 8-10 ohms or at approximately less than 1 ohm. For example, if a high impedance inter-layer short is 190 ohms and the real load is 10 ohms, the resulting or combined impedance is 9.5 ohms [(190×10)/(190+10)], thus the high impedance interlayer short may be virtually undetectable. This is referred to as the real load effect. To avoid the real load effect, a destination relay (not shown) may be placed in the destination module **120**. The destination relay may be timed to delay a connection to the real load on a power up sequence while the DWI component **340** performs its tests, thereby eliminating the 8-10 ohm limitation.

Regarding the detectable inter-layer impedance range between return conductors **210**, **215** and grounding conductors **220**, **225**, the DWI component **340** may accurately detect an inter-layer impedance as high as approximately 5000 ohms prior to the full electrification of the flat wire **105**.

The DWI component **340** may limit or eliminate the detection of false alarms by performing pre-testing on the flat wire **105** prior to testing the flat wire **105** for inter-layer shorts. The DWI component **340** may also limit or eliminate the detection of false alarms by performing post-testing on the flat wire **105** after testing the flat wire **105** for inter-layer shorts. For pre-testing the flat wire **105**, the source/sense circuit **900** may monitor the conductors of the flat wire **105** for a voltage signal prior to transmitting a voltage-based test signal onto the flat wire **105**. If a voltage signal is detected on one of the conductors of the flat wire **105** prior to applying a test signal to the flat wire **105**, then the source/sense circuit **900** may wait for the flat wire **105** to de-energize before applying a test signal to the flat wire **105**. For post-testing of the flat wire **105**, after the flat wire **105** has been tested with voltage-based test signals, the source/sense circuit **900** may continue to monitor the conductors of the flat wire **105** for a voltage signal. Further voltage-based testing of the flat wire **105** using test signals may not be permitted as long as there is a voltage signal detected on one of the conductors of the flat wire **105**.

The voltage-based method of testing the load side of a flat wire **105** for miswires and wire faults may be implemented by devices other than the DWI component **340** of an ASD **100**. For example, the voltage-based method may be particularly useful in a general purpose portable flat wire test system, such as a portable handheld flat wire testing device.

According to another aspect of the invention, the DWI component **340** may utilize one or more current-based methods to identify or locate line side faults or miswires of a flat wire **105** connected to an ASD **100**. Before the relay **310** of the ASD **100** is closed, thereby allowing the flat wire **105** to be electrified, the DWI component **340** may use a current-based method to test the flat wire **105** on the load side and determine whether the flat wire **105** has been connected or wired properly. Determining whether the flat wire **105** is connected properly prior to the full electrification of the flat wire **105** may help prevent electrocution, other bodily harm, or property damage caused by a miswire. By using a current-based method of the DWI component **340**, the DWI component **340** and/or the control unit **312** may determine whether a flat wire

**105** has been installed correctly before the flat wire **105** is ever electrified. The DWI component **340** and/or the control unit **312** may also determine whether any faults exist in the flat wire **105** before the flat wire **105** is electrified.

As desired in various embodiments, the DWI component **340** illustrated in FIG. **9**A may be adapted for use with other types of wiring, for example, a conventional wire **107**. In one example embodiment, voltage-based test signals may be communicated onto one conductor **250**, **255**, **260** of a conventional wire **107** and one or more other conductors **250**, **255**, **260** of the conventional wire **107** may be tested for a return signal. In this regard, shorts may be detected in the conventional wire **107**.

FIG. **9**B is a schematic diagram of a current-based DWI component **340** that may be incorporated into an ASD **100** according to an illustrative embodiment of the invention. As a preliminary matter, it may be noted that FIG. **9**B depicts a different source device **103** and destination device **117** than that shown in FIG. **3**. In FIG. **9**B, the line side power source **115** is incorporated into the source device **103** and the load side destination **125** is incorporated into the destination device **117**. Such a situation might occur, for example, if the source device **103** included a standard electrical plug that may be plugged into an electrical outlet and if the destination device **117** included one or electrical outlets.

As shown in FIG. **9**B, the DWI component **340** may be in communication with one or more excitation or drive circuits **905**, **910** and one or more sense circuits **915**, **920**, **925** that are used to detect miswires and/or wire faults in the flat wire **105**. The excitation circuits **905**, **910** and the sense circuits **915**, **920**, **925** may be included in or controlled by the DWI component. Alternatively, the excitation circuits **905**, **910** and the sense circuits **915**, **920**, **925** may be included in the wire I/O interface **311**, and the DWI component **340** may be in communication with the wire I/O interface **311** and the excitation circuits **905**, **910** and sense circuits **915**, **920**, **925**. The DWI component **340** may determine whether a flat wire **105** connected to the ASD **100** has been properly terminated prior to the electrification of the flat wire **100**. The DWI component **340** depicted in FIG. **9**B is designed to be used in conjunction with an electrical flat wire including an electrifiable conductor **205** and two return conductors **210**, **215** formed on opposing sides of the electrifiable conductor **205**. The electrical flat wire may further include two grounding conductors **220**, **225** formed on opposing sides of the combined electrifiable conductor **205** and return conductors **220**, **225**. A DWI component **340** according to the invention may be used in conjunction with any flat wire (and/or any conventional wire), regardless of the number and type of conductors contained in that flat wire.

Referring to FIG. **9**B, the DWI component **340** may test the flat wire **105** for miswires by transmitting a current-based signal over one conductor of the flat wire **105** and testing one or more of the other conductors of the flat wire **105** for a return signal. For example, the associated conductor of the loop may be tested for a current indicating that the flat wire **100** is wired correctly. For instance, the DWI component **340** may transmit a current-based signal over a first grounding conductor **220** and then monitor a second grounding conductor **225** for a current indicating that the grounding conductors **220**, **225** are wired correctly. Alternatively, the DWI component **340** may transmit a current-based signal over a first return conductor **210** and then monitor a second return conductor **215** for a current indicating that the return conductors **210**, **215** are wired correctly. If the grounding conductors **220**, **225** and return conductors **210**, **215** are wired correctly, then the DWI component **340** may presume that the electrifiable conductor **205** of the flat wire **105** is wired correctly. Alternatively, the DWI component **340** may perform additional tests to verify that the flat wire **105** is terminated properly, as discussed in greater detail below with reference to FIG. **13**. The current that is tested for may be a predetermined threshold current, which may be, for example, 10 milliamps. If the current detected on the associated conductor of a flat wire loop is less than 10 milliamps, the loop may not be wired or terminated correctly at the destination module **120**.

A method and circuit for determining whether the grounding conductors **220**, **225** of a flat wire **105** have been wired correctly will now be described in greater detail. A similar method may be used to determine whether the return conductors **210**, **215** have been wired correctly. In order to test for correct wiring, a ground excitation circuit **905** under control of the DWI component **340** (and/or the control unit **312**) may transmit a current signal over a first grounding conductor **220**. The ground excitation circuit **905** may be an excitation current transformer or any other suitable device capable of transmitting a signal over a first grounding conductor **220** including, but not limited to, multiplexers, isolators, and relays. In order to transmit a current signal onto the first grounding conductor **220**, a test signal may be used to drive a voltage-to-current converter, which in turn forces the current through the primary windings of the current transformer in the ground excitation circuit **905**. Additionally, in order to minimize the magnitude of the excitation placed on the flat wire **105**, the signal transmitted by the ground excitation circuit **905** may be at a frequency much greater than 50 or 60 Hz, which is the frequency typically carried over electrical wires. According to an aspect of the invention, the frequency of the signal transmitted by the ground excitation circuit **905** may be at a frequency of approximately 1000 Hz or greater. The current-based signal communicated or transmitted onto the first grounding conductor **220** may be part of an alternating signal that is used to simultaneously test both the grounding conductor loop and the return conductor loop, as described above with reference to FIG. **8**. Alternatively, the current-based signal used to test the grounding conductor loop may be a separate signal than that used to test the return conductor loop.

After a signal has been transmitted over a first grounding conductor **220**, if the grounding conductors **220**, **225** are properly terminated, then the signal will pass through the destination module **120** and return to the source module **110** via the second grounding conductor **225**. A ground sense circuit **915** connected to the second grounding conductor **225** may be used to detect a current present on the grounding conductors **220**, **225**. The ground sense circuit **915** may be a sensing current transformer or it may be any other suitable device capable of sensing a current including, but not limited to, resistors, isolators, and Hall Effect devices.

The DWI component **340** may also determine whether the return conductors **210**, **215** have been wired correctly on the load side. In order to test for correct wiring, a return excitation circuit **910** under control of the DWI component **340** transmits a current-based signal over a first return conductor **210**, in the same manner as the ground excitation circuit **905** transmits a signal over a first grounding conductor **220**. The current-based signal communicated or transmitted onto the first grounding conductor **220** may be part of an alternating signal that is used to simultaneously test both the grounding conductor loop and the return conductor loop, as described above with reference to FIG. **8**. Alternatively, the current-based signal used to test the return conductor loop may be a separate signal than that used to test the grounding conductor loop. After a signal has been transmitted over a first return conductor **210**, if the return conductors **210**, **215** are properly terminated, then the signal will pass through the destination module **120** and return to the source module **110** via the second return conductor **215**. A return sense circuit **920** connected to the second return conductor **215** may be used to detect a current present on the return conductors **210**, **215**. The return sense circuit **920** may be a sensing current transformer or it may be any other suitable device capable of sensing a current including, but not limited to, resistors, isolators, and Hall Effect devices.

According to an aspect of the invention, the DWI component **340** may also determine that the flat wire **105** is not terminated properly if a current is detected on a conductor of the flat wire **105** other than the conductors being tested in any given loop. As explained in greater detail below, such a situation may also indicate a wire fault. In certain embodiments, the DWI component **340** may differentiate between a miswire and a wire fault based upon the magnitude of a current signal detected on one of the other conductors and/or based on the number of other conductors on which a current signal is detected. For example, if a test current is applied to a return conductor **210** and a current that is approximately equal to the test current is detected on the electrifiable conductor **205**, then the DWI component **340** may determine that the electrifiable conductor **205** and the other return conductor **215** have been miswired. As another example, if a test current is applied to a return conductor **210** and a current signal is detected on all of the conductors of the flat wire **105** (the detected current signals may have a lower amplitude than the test current), then the DWI component **340** may determine that a wire fault exists and that the conductors of the flat wire **105** have been shorted together.

According to another aspect of the invention, the DWI component **340** may use the current-based method to determine whether there are any wire faults or inter-layer shorts present on the flat wire **105** prior to the electrification of the flat wire **105**. The DWI component **340** may detect inter-layer shorts on a non-electrified flat wire **105** by transmitting a low level current through a single flat wire conductor, such as the electrifiable conductor **205**, or through one set of flat wire **105** layers, such as the return conductors **210**, **215**. Then, the DWI component **340** may monitor one or more of the other flat wire **105** layers for a return current. For instance, a current may be transmitted on the one or more return conductors **210**, **215** of the flat wire **105**. The DWI component **340** may then monitor the electrifiable conductor **205** and the one or more grounding conductors **220**, **225** of the flat wire **105** for a return current. As another example, a current may be transmitted on the electrifiable conductor **205** of the flat wire **105**, and the DWI component **340** will monitor the one or more return conductors **210**, **215** and the one or more grounding conductors **220**, **225** of the flat wire **105** for a return current.

The DWI component **340** may combine testing for miswires in the flat wire **105** with testing for wire faults or inter-layer shorts on the flat wire **105**. For example, with reference to FIG. **9**B, when a current-based test signal is transmitted onto the first grounding conductor **220** by the ground excitation circuit **905**, the sense circuits **915**, **920**, **925** may be used to determine whether the flat wire **105** contains any miswires or inter-layer shorts. As previously mentioned, the ground sense circuit **915** may be used to determine whether or not the grounding conductors **220**, **225** have been properly terminated at the load side. Additionally, the return sense circuit **920** and an electrifiable (or hot) sense circuit **925** may be used to monitor the flat wire **105** for a miswire or inter-layer short. If a current-based signal is detected on the second return conductor **210** by the return sense circuit **920**, then the DWI component **340** may determine that there is an inter-layer short between one or more of the grounding conductors **220**, **225** and one or more of the return conductors **210**, **215**. Similarly, if a current-based signal is detected on the electrifiable conductor **205** by the electrifiable sense circuit **925**, the DWI component **340** may determine that there is an inter-layer short between one or more of the grounding conductors **220**, **225** and the electrifiable conductor **205**.

As an example, a test current of approximately 10 milliamps (mA) may be transmitted onto the first grounding conductor **220** of the flat wire **105** by the ground excitation circuit **910**. If the ground sense circuit **915** detects a signal of approximately 10 milliamps on the second grounding conductor **220**, then the DWI component **340** may determine that the grounding conductors **220**, **225** are properly terminated. If, however, the ground sense circuit **915** does not detect a signal of approximately 10 milliamps on the second grounding conductor **220**, then the DWI component **340** may determine that the grounding conductors **220**, **225** are not properly terminated and the DWI component **340** may prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. Additionally, if a current is detected on either the second return conductor **215** by the return sense circuit **920** or on the electrifiable conductor **205** by the electrifiable sense circuit **925**, then the DWI component **340** may determine that there is an inter-layer short in the flat wire **105**. The DWI component **340** may then prevent the relay **310** from being closed to prevent electrification of the flat wire **105**.

As desired in various embodiments, the DWI component **340** illustrated in FIG. **9**B may be adapted for use with other types of wiring, for example, a conventional wire **107**. In one example embodiment, voltage-based test signals may be communicated onto one conductor **250**, **255**, **260** of a conventional wire **107** and one or more other conductors **250**, **255**, **260** of the conventional wire **107** may be tested for a return signal. In this regard, shorts may be detected in the conventional wire **107**.

The combination of excitation circuits **905**, **910** and sense circuits **915**, **920**, **925** shown in FIG. **9**B is simply one combination of these circuits that may be used in accordance with certain embodiments of the invention. Excitation circuits and/or sense circuits may be used to transmit a signal onto or monitor any of the conductors of the flat wire **105**. Using the example above, when a test signal is transmitted onto the first grounding conductor **220**, an additional sense circuit may be used to monitor the first return conductor **210** of the flat wire **105** for a return signal that indicates an inter-layer short between one or more of the grounding conductors **220**, **225** and the first return conductor **210**. Because the two return conductors **210**, **215** form a loop if they are wired correctly, any inter-layer short between one or more of the grounding conductors **220**, **225** and the first return conductor **210** would also be detected by the return sense circuit **920** that is monitoring the second return conductor **215**.

The excitation circuits **905**, **910** and the sense circuit **915**, **920**, **925** may be incorporated into the DWI component **340**. Alternatively, the excitation circuits **905**, **910** and the sense circuits **915**, **920**, **925** may be included in the wire I/O interface **311**, and the DWI component **340** may be in communication with the wire I/O interface **311** either directly or through the control unit **312**.

Additionally, the current-based method of the DWI component **340** may utilize one or more testing relays in conjunction with monitoring the sense circuits **915**, **920**, **925** for a return signal. The testing relays may be used to short one or more conductors or layers of the flat wire **105** together when making a measurement. The shorts created by the testing relays may assist in measuring the current across any two conductors of the flat wire **105**. Accordingly, the testing relays may assist in locating or identifying conductors that have been miswired and/or in localizing flat wire faults. As an example, two testing relays **930**, **935** may be used by the DWI component **340** in conjunction with monitoring the flat wire **105** for miswires and inter-layer shorts. FIG. **9**C is a schematic diagram of one example of a DWI component **340** that utilizes testing relays **930**, **935** in monitoring a flat wire **105** for miswires and inter-layer shorts according to certain embodiments of the invention. As shown in FIG. **9**C, when neither of the testing relays **930**, **935** is actuated or, in other words, neither of the testing relays **930**, **935** is in a closed position, a default state may exist in which both the grounding loop and the return loop are allowed to be completed on the flat wire **105**. While neither of the testing relays **930**, **935** is actuated, the DWI component **340** may test the flat wire **105** for complete grounding and return conductor loops. When the first testing relay **930** is actuated or in a closed position, the return excitation circuit **910** may be connected or shorted to the ground sense circuit **915**, thereby creating half of a loop necessary to check for an inter-layer short between one or more of the return conductors **210**, **215** and one or more of the grounding conductors **220**, **225**. If an inter-layer short exists between one or more of the return conductors **210**, **215** and one or more of the grounding conductors **220**, **225**, then the loop will be complete and the DWI component **340** will detect the inter-layer short. Similarly, when the second testing relay **935** is actuated or in a closed position, the return excitation circuit **910** may be connected or shorted to the electrifiable or hot sense circuit **925**, thereby creating half of a loop necessary to check for an inter-layer short between one or more of the return conductors **210**, **215** and the electrifiable conductor **205**. If an inter-layer short exists between one or more of the return conductors **210**, **215** and the electrifiable conductor **205**, then the loop will be complete and the DWI component **340** will detect the inter-layer short. When the DWI component **340** completes its testing, then both testing relays **930**, **935** may be de-energized back to their original or default states.

FIG. **10** is a flowchart of one example of the operation of a current-based detection method by a DWI component **340**, according to an illustrative embodiment of the invention. The flowchart of FIG. **10** may be associated with the current-based detection method and circuitry described above with reference to FIG. **9**B. Thus, the flowchart of FIG. **10** may be applicable to testing flat wire **105**; however, a similar method may be utilized to test conventional wire **107**. With reference to FIG. **10**, if power is applied to the DWI component **340** at block **1005**, then the DWI component **340** may go to block **1010**. At block **1010**, the DWI component **340** may apply a test signal to the first grounding conductor **220** of the flat wire **105**. Then, the DWI component **340** may go to block **1015** and monitor the remaining conductors of the flat wire **105** for a return signal. At block **1020**, the DWI component may determine whether the grounding conductor loop has been terminated properly by determining whether or not an appropriate return signal is present on the second grounding conductor **225**. If the grounding conductor loop is not determined to be properly terminated, then the DWI component **340** may go to block **1065** and prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. If, however, the grounding conductor loop is determined to be properly terminated at block **1020**, then the DWI component **340** may go to block **1025**. At block **1025**, the DWI component **340** may determine whether or not a short circuit exists between the grounding conductors **220**, **225** and any of the other conductors of the flat wire **105** by determining whether or not a return signal is present on one or more of the electrifiable conductor **205**, the first return conductor **210**, and the second return conductor **215**. If a return signal is detected on any of the conductors other than the grounding conductors **220**, **225**, a wire fault may be present on the flat wire **105**, and the DWI component **340** may go to block **1065** and prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. If, however, no return signal is detected on any of the conductors other than the grounding conductors **220**, **225**, then the DWI component may go to block **1030**.

At block **1030**, the DWI component **340** may apply a test signal to the first return conductor **210** of the flat wire **105**. Then, the DWI component **340** may go to block **1035** and monitor the remaining conductors of the flat wire **105** for a return signal. At block **1040**, the DWI component determines whether the return conductor loop has been terminated properly by determining whether or not an appropriate return signal is present on the second return conductor **215**. If the return conductor loop is not determined to be properly terminated, then the DWI component **340** may go to block **1065** and prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. If, however, the return conductor loop is determined to be properly terminated at block **1040**, then the DWI component **340** may go to block **1045**. At block **1045**, the DWI component **340** may determine whether or not a short circuit exists between the return conductors **210**, **215** and any of the other conductors of the flat wire **105** by determining whether or not a return signal is present on one or more of the electrifiable conductor **205**, the first grounding conductor **220**, and the second grounding conductor **225**. If a return signal is detected on any of the conductors other than the return conductors **210**, **215**, then a wire fault may be present on the flat wire **105**, and the DWI component **340** may go to block **1065** and prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. If, however, no return signal is detected on any of the conductors other than the return conductors **210**, **215**, then the DWI component may go to block **1050**.

At block **1050**, the DWI component **340** may apply a test signal to the electrifiable conductor **205** of the flat wire **105**. Then, the DWI component **340** may go to block **1055** and monitor the remaining conductors of the flat wire **105** for a return signal. At block **1060**, the DWI component **340** may determine whether or not there is a return signal in any of the other conductors of the flat wire **105**. A return signal in any of the other conductors may indicate a miswire of the electrifiable conductor **205** or a short between the electrifiable conductor **205** and one of the other conductors of the flat wire **105**. If, at block **1060**, a return signal is detected on one of the other conductors of the flat wire **105**, then the DWI component **340** may go to block **1065** and prevent the relay **310** from being closed to prevent electrification of the flat wire **105**. If, however, no return signal is detected on any of the other conductors of the flat wire **105** at block **1060**, then the DWI component **340** may go to block **1070** and allow the relay **310** of the ASD **100** to be closed. Alternatively, a DWI component flag or state may be set, and the flag or state may be used by the ASD **100** in conjunction with the flags or states from other tests to determine whether or not the relay **310** is allowed to close.

The tests performed by the current-based method of the DWI component **340** do not necessarily have to be performed in the order set forth in the logic of FIG. **10**, but instead may be performed in any suitable order. Additionally, the DWI component **340** does not have to conduct each test set forth in FIG. **10**, but instead may conduct less than all of the tests set forth in FIG. **10**. If any test results in the execution of block **1065**, then the DWI component **340** may still perform the remaining tests and may record the outcome of each test, or at least the ones that result in a positive miswire or fault indication. Additionally, if a miswire or fault is detected by the DWI component **340**, an indicator may be stored by the DWI component **340** or by the control unit **312**, and the indicator may include information as to which test(s) resulted in the detection of a miswire. This indicator may then be transmitted by the ASD **100** to another device such as a second ASD **100**, a central monitoring device, or a computer. The DWI component **340** and/or the control unit **312** may also cause additional data, for example, measurements data taken by the components of the DWI component **340**, to be stored in an appropriate memory, such as the memory **405** of the control unit **312**.

FIG. **11** is a schematic diagram of an alternative DWI component **340** that may be incorporated into an ASD **100**, according to an embodiment of the invention. As shown, the ASD **100** may include more than one relay **310**, **1105** that may be utilized to test the flat wire **105**. With reference to FIG. **11**, the ASD **100** may control the actuation of a first relay **310** in order to control the communication of an electrical power signal from the line side power source **115** to the electrifiable conductor **315** of the flat wire **105**. The ASD **100** may also control the actuation of a second relay **1105** in order to control the communication of an electrical signal from the line side power source **115** to one or more return conductors **210**, **215** of the flat wire **105**. According to an aspect of the invention, the two relays **310**, **1105** may be actuated independently of one another. For example, the second relay **1105** may be utilized in association with the DWI component **340** in order to test the flat wire **105** for miswires and/or wire faults. The second relay **1105** may be closed for a predetermined period of time, for example, one half cycle of the electrical power signal of the line side power source **115**, thereby allowing an electrical signal to be communicated onto one or more of the return conductors **210**, **215**. In certain embodiments, the electrical signal communicated onto one or more of the return conductors **210**, **215** may be the electrical power signal communicated from the line side power source **115** or, alternatively, the electrical signal may be an altered version of the line side power source signal. For example, the line side power source signal may be stepped down or stepped up by an appropriate transformer and/or current limited by an appropriate resistor device prior to being communicated onto one or more of the return conductors **210**, **215**.

Once an electrical signal has been communicated onto one or more of the return conductors **210**, **215** of the flat wire **105**, one or more sensors **1110**, **1115**, **1120** associated with the DWI component **340** may be utilized to test the flat wire **105** for return signals. The one or more sensors **1110**, **1115**, **1120** may be appropriate voltage or current sensors, as previously discussed. For example, the one or more sensors **1110**, **1115**, **1120** may be current transformers. As shown in FIG. **11**, one or more sensors **1110**, **1115**, **1120** may be utilized to test the electrifiable conductor **205**, one or more of the return conductors **210**, **215**, and one or more of the grounding conductors **220**, **225** for return signals. Because the return conductors **210**, **215** and the grounding conductors **220**, **225** form respective loops if they are properly terminated at the destination module **120**, in certain embodiments, a single sensor may be respectively utilized for each pair of conductors. Additionally, in certain embodiments, the sensors **1110**, **1115** utilized to test for a return signal on the electrifiable conductor **205** and one or more of the return conductors **210**, **215** may be the current sensors utilized by the GFCI component **315**.



The DWI component **340** of FIG. **11** may test the flat wire **105** for miswires and/or wire faults in a similar manner to that described above for the return conductors with reference to FIG. **10**. For example, following the communication of an electrical signal onto one or more of the return conductors **210**, **215**, miswires and/or wire faults may be identified by the return signals that are detected by the one or more sensors **1110**, **1115**, **1120**. If a return signal is detected on the electrifiable conductor **205** and/or one or more of the grounding conductors **220**, **225**, then a miswire and/or wire fault may be present on the flat wire **105**. Additionally, if an electrical signal is applied to the first return conductor **210** and a return signal is not detected on the second return conductor **215**, then a miswire may be identified in the flat wire **105**.

The ASD **100** may include any number of relays and an electrical signal may be communicated onto any conductor(s) of the flat wire **105** for testing. For example, a relay may be utilized to allow an electrical signal to be communicated onto one or more of the grounding conductors **220**, **225** of the flat wire **105**, and the flat wire **105** may be tested for return signals in a similar manner as that described above with reference to FIG. **11**. The use of more than one relay may assist in preventing bounce and wear and tear on one or more of relays. For example, if a relay **1105** is utilized to control the communication of an electrical signal onto one or more of the return conductors **210**, **215**, then the relay **1105** may not be subject to the bounce and/or wear and tear that the relay **310** utilized in association with the electrifiable conductor **205** is subject to.

FIG. **12** is a schematic diagram of an ASD **100** and a DWI component **340** that may be utilized to detect high impedance shorts or wire faults in a wire **102**, according to an embodiment of the invention. The ASD **100** and DWI component **340** illustrated in FIG. **12** may be used to test many different types of wires, such as an electrical flat wire **105** or a conventional wire **102**. With reference to FIG. **12**, more than one relay **310**, **1205** may be incorporated into the ASD **100**. A first relay **310** may be utilized to control the communication of an electrical power signal from the line side power source **115** onto the wire **102**. A second relay **1205** may be utilized to control the communication of a test signal onto the wire **102**. The test signal may be a current limited version of the electrical power signal. For example, the electrical power signal may be passed through an appropriate resistance device **1210** (e.g., a resistor) in order to limit the current of the termination test signal. As desired, the current may be limited to any appropriate value, for example, a current that is between approximately 6 mA and approximately 100 mA. According to an aspect of the invention, the current may be limited to approximately 20 mA. Additionally, other parameters of the test signal may be altered by appropriate circuitry **1215**. For example, the voltage of the test signal may be altered before it is communicated onto the wire **102**. As an example, the voltage of the test signal may be stepped up to a higher voltage value by a suitable transformer before it is communicated onto the flat wire **100**. As another example, the voltage of the test signal may be increased before it is communicated onto the flat wire **100** by an appropriate inversion technique. According to an aspect of the invention, the test signal may have a voltage that is between approximately 120 V and approximately 1000 V, although higher voltage values may be used. Additionally, as desired, the test signal may be either an alternating current signal or a direct current signal, for example, a direct current signal that is obtained by rectifying the electrical power signal received from the line side power source **115**. Furthermore, the test signal may have virtually any frequency. For example, the test signal may have a frequency between approximately 50 Hz and approximately one (1) MHz. According to an aspect of the invention, the test signal may have a frequency of approximately 30 KHz.

The use of a high voltage test signal may assist in detecting high impendence shorts or wire faults on the wire **102**. For example, a high voltage test signal may assist in detecting an arc flash or other arcing condition on a flat wire **105**. The use of a current limited signal may provide for additional safety if there is a wire fault on the wire **102**. Additionally, the use of the test signal described with reference to FIG. **12** by the ASD **100** to test the wire **102** may be used as a proactive safety test independently of or in addition to one or more of the other proactive safety tests described herein or apparent to one or ordinary skill in the art.

The test signal may be communicated onto one or more of the conductors of the flat wire **105** by closing the second relay **1205**. The second relay **1205** may be closed for a predetermined period of time. Virtually any predetermined period of time may be utilized as desired. Additionally, the test signal may be communicated onto any of the conductors of the wire **102**. For example, the test signal may be communicated onto one or more of the return conductors **210**, **215** of a flat wire **105**, as discussed above with reference to FIG. **11**. As another example, the test signal may be communicated onto one or more of the grounding conductors **220**, **225** of a flat wire **105**. As yet another example, the test signal may be communicated onto the electrifiable conductor **205** of a flat wire **105**. Other examples include the communication of a test signal onto at least one conductor of a conventional wire **107**, such as onto the electrifiable conductor **250**, onto the return conductor **255**, or onto the grounding conductor **260**. After the test signal has been communicated onto one or more conductors of the wire **102**, the DWI component **340** may monitor one or more conductors of the wire **102** for a return signal in a similar manner as that discussed above with reference to FIG. **11**. The detection of a return signal may indicate the presence of a miswire and/or a wire fault on the wire **102**. For example, if the test signal is communicated onto the first return conductor **210** of a flat wire **105**, then the detection of a return signal on the electrifiable conductor **205** and/or one or more of the grounding conductors **220**, **225** may indicate a miswire and/or a wire fault on the flat wire **105**. If a miswire or wire fault is detected by the DWI component **340**, then the relay **310** may be maintained in an opened position, thereby preventing the full electrification of the monitored wire **102**. Additionally, the second relay **1205** may be maintained in an opened position. If, however, no miswires or wire faults are detected by the DWI component **340**, then the first relay **310** may be permitted to be closed, thereby allowing the full electrification of the wire **102**.

As previously mentioned, additional tests may be conducted on the electrifiable conductor of a monitored wire **102**, such as the electrifiable conductor **205** of a flat wire **105** or the electrifiable conductor of a conventional wire **107**, in order to determine that the electrifiable conductor has been properly terminated. These additional tests are described herein as reactive tests; however, proactive tests may also be utilized prior to the full electrification of the wire **102**. These tests may also be associated with the load side wire integrity. Accordingly, the DWI component **340** may include both reactive and proactive elements.

FIG. **13** is a schematic diagram of one example circuit that may be utilized to test for a proper flat wire termination at a destination module **120**, according to an embodiment of the invention. FIG. **13** is described herein with reference to flat wire, such as a flat electrical wire **105**; however, a similar circuit may be utilized to test other types of wire, such as a conventional wire **107**. With reference to FIG. **13**, during the electrification of the flat wire **105** and/or after the electrification of the flat wire **105**, the ASD **100** may test for a proper termination of the electrifiable conductor **205**. In other words, once the relay **310** has been closed, the ASD **100** may test for an appropriate return signal that indicates that the electrifiable conductor **205** is properly terminated at the destination module **120**. In order to test for a proper termination of the electrifiable conductor **205** at the destination module **120**, an electrical load **1305** may be incorporated into the destination module **120**. The electrical load **1305** may be a passive load that is detectable by the ASD **100**, for example, one or more LED's, one or more resistors, and/or one or more capacitors. The electrical load **1305** may be connected between the electrifiable conductor **205** and one or more of the return conductors **210**, **215** of the flat wire **105**. The electrical load **1305** may have virtually any total impedance that is discernable by one or more current sensing devices included in the ASD **100**.

Once the relay **310** has been closed and an electrical power signal is communicated onto the flat wire **105**, the electrical load **1305** may operate to generate a current on the flat wire **105** that may be detectable by appropriate current sensors of the ASD **100**, for example, the current sensors utilized in association with the DWI component **340**. The generated current may then be detected by one or more appropriate current sensors associated with the ASD **100** and, based at least in part on the amplitude of the detected current, a determination may be made as to whether the electrifiable conductor **205** and/or one or more of the return conductors **210**, **215** have been properly terminated. In other words, if the detected current is above a predetermined threshold value, it may be determined that the electrifiable conductor **205** and/or one or more of the return conductors **210**, **215** have been properly terminated. If, however, the detected current is below the predetermined threshold value, it may be determined that the electrifiable conductor **205** and/or one or more of the return conductors **210**, **215** are not properly terminated, and the relay **310** may be opened, thereby de-energizing the flat wire **105**. Many different predetermined threshold values may be utilized in accordance with the invention, for example, a predetermined threshold value of approximately 20 mA. If an electrical device, such as a lamp or a vacuum cleaner is connected to the destination module **120**, then a greater electrical load **1305** may be present on the flat wire **105**. As discussed earlier, the over-current protection component **325** may de-energize the flat wire **105** if the current on the flat wire **105** exceeds a maximum allowed current, for example, a current of approximately 15 A.

As an example, once the flat wire **105** has been fully electrified, a 120 VAC signal may be communicated over the electrifiable conductor **205** to the destination module **120**. The 120 VAC signal may then be communicated through an electrical load **1305** that is connected between the electrifiable conductor **205** and one or more of the return conductors **210**, **215** in the destination module **120**, thereby generating a current on the flat wire **105**. The current may then be detected at the ASD **100** and compared to a predetermined threshold value in order to verify that the flat wire **105** is terminated properly. If an LED is utilized as part of the electrical load **1305** in the destination module **120**, the LED may also provide a visual indication of a proper termination for the flat wire **105**. Furthermore, as desired, a similar test as that discussed above with reference to FIG. **13** for the electrifiable conductor **205** may also be conducted on one or more of the other conductors of the flat wire **105**.

Although the tests to detect a properly terminated electrifiable conductor are described above as reactive tests, one or more proactive tests may additionally or alternatively be utilized prior to the full electrification of the flat wire **105**. For example a voltage test signal may be communicated onto the electrifiable conductor **205** of the flat wire **105** and the voltage test signal may be communicated through a passive load in the destination module **120** prior to being returned to the ASD **100**. The passive load may cause a detectable voltage drop in the flat wire **105**. An appropriate voltage sensor in the ASD **100** may then detect the voltage drop across the passive load and determine whether or not the electrifiable conductor **205** has been properly terminated.

The destination module **120** may include an appropriate relay that may prevent the voltage test signal from being communicated to an electrical device, such as a lamp or vacuum cleaner. In other words, the passive load may be the only load connected to the flat wire **105** at the destination module **120** during the proactive testing of the flat wire **105**. If the voltage of the termination test signal has been stepped up prior to being communicated onto the flat wire **105**, it may be easier to detect the electrical load **100**. Based at least in part on the voltage detected at the ASD **100**, the DWI component **340** and/or the control unit **312** may determine whether or not the electrifiable conductor **205** has been properly terminated. As desired, other conductors of the flat wire **105** may be tested for proper termination utilizing appropriate voltage signals.

As desired in various embodiments, other safety components may be included or incorporated into or associated with the ASD **100**. The safety components described herein are merely examples of safety components that may be associated with the ASD **100**. Other safety components will be readily apparent to those of ordinary skill in the art. Additionally, the various safety components may incorporate, include, and/or be associated with a wide variety of different logic, software modules, software components, firmware, hardware components, and/or circuitry as desired in various embodiments of the invention.

Additionally, in certain embodiments of the invention, a variety of safety components or other features may be included in a destination device **117**. As discussed above, a destination device **117** may include a passive load that assists in the testing of the proper termination of the flat wire **105**. The destination device **117** may also include one or more safety components that may be utilized to test wire, such as flat wire **105** or conventional wire **107**, that has been connected downstream from the destination device **117**, as discussed below with reference to FIG. **19**. The one or more safety components that may be included may be similar to one or more of the safety components discussed above for the ASD **100**. A destination device **117** may also include a light emitting diode (LED) or another suitable device that may indicate to a user when power is being supplied to the destination device **117**. A destination device **117** may also include suitable surge protection devices and associated fuses that may prevent a dangerous high current signal from being passed through the destination device **117**. For example, the destination device **117** may include a suitable surge protection device between the electrifiable conductor **205** and the return conductors **210**, **215** of a flat wire **105**. As another example, the destination device **117** may include a suitable surge protection device between the electrifiable conductor **205** and the grounding conductors **220**, **225** of a flat wire **105**. As other examples, suitable surge protection may be included between the electrifiable conductor **250** and the return conductor **255** of a conventional wire **107** or, similarly, between the electrifiable conductor **250** and the grounding conductor **260** of a conventional wire **107**.

A destination device **117** and/or the ASD **100** may also include a battery backup that permits at least the conducting of proactive tests on the wire **102** in the event of a power outage. The battery backup may be any type of suitable battery, such as a rechargeable battery that may be charged while power is provided to the ASD **100** and/or the destination device **117** from the line side power source **115**. Additionally, as previously mentioned, a destination device **117** and/or the ASD **100** may include any number of electrical sockets. Other features that may be incorporated into a destination device **117** will be apparent to those of ordinary skill in the art.

Safety is an important consideration in the design of wiring systems that can carry dangerous voltage levels, especially when there is a possibility of a penetration of an electrifiable conductor, such as the electrifiable conductor **205** of a flat wire **105**. Penetration or compromise of a flat wire **105** by objects such as nails, screws, drill bits, knife blades, saw blades, scissors, staples, darts, bullets, toys, etc. should be considered.

The flat wire **105** described herein, for purposes of disclosing the invention, may itself be designed to be safe if it is penetrated. Fire protection and electric shock safety are based on limiting the voltage, and therefore the current in the flat wire **105** while expediting the trip time of a primary safety device such as a circuit breaker or a fuse in a branch circuit main box. Secondary protection may also be provided by the ASD **100** of the invention.

The flat wire **105** may be designed to produce a short between a first grounding conductor **220**, a first return conductor **210**, an electrifiable conductor **205**, a second return conductor **215**, and a second grounding conductor **225** (G-N-H-N-G) in that sequence upon penetration. With as much as four times the conductance ultimately tied to earth ground, a voltage divider is formed favoring the ground voltage over the line or hot voltage. Repeated tests show that voltages present at the site of penetrations of the flat wire **105** do not exceed approximately 50 VAC for longer than a primary safety device's trip time, which is typically under 25 milliseconds. Furthermore, the voltage present at the site of penetrations does not exceed approximately 50 VAC for longer than the trip time of a secondary safety device such as the ASD **100**, which may be approximately 8 milliseconds.

Penetration may occur through the broadside or the flat surface of a flat wire **100** by sharp objects. Alternatively, penetration may occur through an edge of the flat wire **100** by an object such as a knife blade or drywall saw. In either situation, the resulting short may cause a high current to be produced at a low voltage for a short time (less than the trip time). Startle effect, or sound burst, and localized heating may be minimized due to the nature of the protective layered flat wire **105**.

FIGS. **14**A-F are a series of diagrams which depict an example of the dynamics of a nail or tack penetration of a live multi-planar flat wire **105**. Again, protective layered flat wire **105** has a distinct advantage over conventional wire by assuring that a penetrating object **1400**, such as a nail, first passes through a grounding conductor (G1) **220**, then a return or neutral conductor (N1) **210** prior to any contact with the hot electrifiable conductor **205**.

FIG. **14**A depicts a situation in which a penetrating object **1400** has only penetrated one grounding conductor **220** of the flat wire **105**. Similarly, FIG. **14**B depicts a situation in which a penetrating object **1400** has penetrated only one grounding conductor **220** and one return conductor **210**. In both FIGS. **14**A and **14**B, the electrifiable conductor **205** has not yet been penetrated. Accordingly, in both FIGS. **14**A and **14**B, there may be no voltage or current present on the penetrating object

**1400**. Additionally, the current present on the electrifiable conductor **205** of the flat wire **105** may be some normal load current. The normal load current present on the electrifiable conductor **205** may be a current which is less than approximately 15 amps in a standard United States branch application or which is less than approximately 6 amps in a standard European branch application.

FIG. **14**C depicts a situation in which the penetrating object **1400** has shorted the electrifiable conductor **205**, one of the return conductors **210** and one of the grounding conductors **220**. Similarly, FIG. **14**D depicts a situation in which the penetrating object **1400** has shorted the electrifiable conductor **205**, both of the return conductors **210**, **215** and one of the grounding conductors **220**. FIG. **14**E depicts a situation in which the penetrating object **1400** has shorted the electrifiable conductor **205**, both of the return conductors **210**, **215** and both of the grounding conductors **220**, **225**. In each of FIGS. **14**C-**14**E, the short circuit created in the flat wire **105** between the electrifiable conductor **205** and any of the other conductors **210**, **215**, **220**, **225** may act as a voltage divider until a primary safety device such as a circuit breaker or a secondary safety device such as an ASD **100** trips. In each of FIGS. **14**C-**14**E, there may be a relatively low voltage present on the penetrating object **1400**. The low voltage may be less than approximately 50 VAC on a standard 120 VAC wire, and the low voltage may be less than approximately 100 VAC on a standard 240 VAC line. Additionally, in each of FIGS. **14**C-**14**E, the current present on the electrifiable conductor **205** may exceed approximately 100 amps until the primary or secondary safety device (ASD) **100** trips. There also may be a current present on either of the grounding conductors **220**, **225** and/or on either of the return conductors **210**, **215** which will also facilitate the tripping of the ASD **100**.

The time for penetrating from an outer grounding layer **220** to an electrifiable conductor **205** (FIGS. **14**A-**14**C) may typically be under one millisecond, which is only a fraction of a typical trip time for a primary safety device such as a circuit breaker. Similarly, the time to continue penetration from an electrifiable conductor **205** to the backside grounding layer **225** (FIGS. **14**C-**14**E) may also be relatively short. The short circuit created during the penetration may be of a continuous nature. The continuous nature of the short circuit may be due to two primary factors: firstly, the conductor contact at the sides of the penetrating object **1400** is maintained by the insulation displacement process during penetration and secondly, by the molten copper in the proximity of the contact area once the short begins.

FIG. **14**F depicts a penetration after a penetrating object **1400** has been removed from the flat wire **105**. If the circuit breaker has been reset prior to the flat wire **105** being electrified, then some additional damage may be done to the flat wire **105** before the circuit breaker trips again; however, if an ASD **100** is connected to the flat wire **105**, then any additional damage may be prevented. The proactive safety components of the ASD **100** may determine that a fault exists on the flat wire **100** prior to allowing the flat wire **100** to be fully electrified. For example, when testing the flat wire **105** prior to electrification, the DWI component **340** of the ASD **100** may determine that a short exists between the conductors or layers of the flat wire **105**. The ASD **100** will then prevent the flat wire **100** from being electrified.

FIG. **15** is a representative graph of the voltage and current waveforms present during a penetration of a flat wire **105**. The voltage waveform present on the penetrating object **1400** and current waveform present on the electrifiable conductor **205** may be captured by an oscilloscope, such as a Gould Ultima 500 oscilloscope. For this example, the penetrating object **1400** was a nail of a 4d common size and the circuit breaker used was a common 20 amp GE circuit breaker. As shown by FIG. **14**, the trip time for the circuit breaker may be approximately 12 to 25 milliseconds when the penetrating object **1400** penetrates the flat wire **105**. Note that the circuit breaker trip time may be less than the period for one cycle of a standard 120 VAC, 60 Hz electrical wire. The trip time for an ASD **100** connected to the flat wire **105** may also be less than the period for one cycle of a standard 120 VAC, 60 Hz electrical wire. Additionally, the trip time of the ASD **100** may be less than the trip time of the circuit breaker. The trip time of the ASD **100** may be, for example, approximately 8 milliseconds or less, causing the ASD **100** to trip before the tripping of the circuit breaker. After the ASD **100** trips, causing the flat wire **105** to be de-energized, the circuit breaker may or may not trip.

FIGS. **16**A-**16**D are a series of diagrams which depict examples of the dynamics of a penetration of a non-live multi-planar flat wire **105**. FIG. **16**A shows the inter-layer shorts that occur when a penetrating object **1600**, such as a nail, penetrates the flat wire **105**. Without electrification, the conductors of the flat wire **105** may not experience additional damage or fusion from high currents; however, multiple inter-layer shorts may be caused. FIG. **16**B shows the residual inter-layer shorts after the penetrating object **1600** has been removed from the flat wire **105**. The DWI component **340** of an ASD **100** connected to the flat wire **105** may be able to detect this inter-layer short prior to allowing the flat wire **105** to be fully electrified. The DWI component **340** may also be able to determine that the layer loops of the flat wire **105**, such as the grounding layer loop or the return conductor layer loop, are incomplete prior to allowing the flat wire **105** to be fully electrified. The proactive safety components of the ASD **100** may prevent flashes or plumes (e.g., arc flashes) which may occur upon electrification of the flat wire **105** by recognizing defects prior to allowing the flat wire **105** to be fully electrified.

If the penetrating object **1600** penetrated the flat wire **105** after the flat wire **105** had been electrified, then the reactive safety components including the GFCI component **315** and the ground current monitoring component **330** may detect the flaw in the flat wire **105** and open the relay **310** of the ASD **100**, thereby de-energizing the flat wire **105**.

FIG. **16**C depicts the transverse cut of a flat wire **105** by a cutting object **1605**, such as a pair of scissors. In FIG. **16**C, the cutting object **1605** is shown still in the flat wire **105** during the cut. FIG. **16**D depicts how a partially cut flat wire **105** section would appear once the cutting object **1605** has been removed. The DWI component **340** of an ASD **100** connected to the flat wire **105** may be able to detect the inter-layer shorts created by the cutting object **1605** prior to allowing the flat wire to be fully electrified. Alternatively, the DWI component **340** may be able to determine that the layer loops of the flat wire **105**, such as the grounding layer loop or the return conductor layer loop, are incomplete prior to allowing the flat wire **105** to be fully electrified. The proactive safety components of the ASD **100** may prevent flashes or plumes (e.g., arc flashes) which may occur on the flat wire **105** by recognizing defects prior to allowing the flat wire **105** to be fully electrified.

If the cutting object **1605** cuts the flat wire **105** after the flat wire **105** has been electrified, then the reactive safety components including the GFCI component **315** and the ground current monitoring component **330** may detect the flaw in the flat wire **105** and open the relay **310** of the ASD **100**, thereby de-energizing the flat wire **105**.

The various safety components of the ASD **100** may share various circuits. Although the various safety components are described herein as individual components, one or more of the safety components may utilize common circuits. For example, the ASD **100** may include only one excitation circuit and one sense circuit that is used as needed by each of the safety components of the ASD **100**.

The sharing of circuits by the various components of the ASD **100** may facilitate the construction of a compact device. Accordingly, the ASD **100** may be placed in a compact enclosure such as in a wall box or cavity that is roughly the size of a common electrical outlet. For example, an ASD **100** may be placed in a wall cavity that is the size of the cavity used for an electrical outlet. The ASD **100** may be powered by a conventional in-wall electrical wire. Alternatively, an ASD **100** may be plugged into a conventional wall receptacle outlet and powered by that outlet. If the ASD **100** is to be plugged into an outlet, the source device **103** may include, for example, a plug, such as a traditional three-prong electrical plug, that may be inserted into the outlet. In such a situation, the plug would be the line side power source **115** for a wire system **101**, and the line side power source **115** would be incorporated into the source device **103**. A wire **102** may then be connected to and monitored by the ASD **100**. Additionally, the ASD **100** may have auxiliary receptacles, or plugs, situated on the exterior surface of the ASD **100**. These plugs may be common two-prong or three-prong plugs and may be used to power electronic devices.

According to an aspect of the invention, the ASD **100** may be configured to receive power and an electrical power signal from a line side power source **115** that is a standard electrical outlet. Additionally, the ASD **100** may be configured to prevent the communication of the electrical power signal onto the wire **102** without the electrical power signal first being communicated through the ASD **100**. Accordingly, the ASD **100** may conduct one or more tests on the wire **102** prior to electrification of the wire **102**, during the electrification of the wire **102** and/or subsequent to the electrification of the wire **102**.

FIG. **17**A is a schematic diagram of one example of a source device connection to an electrical outlet **1705** and a flat wire **105**, according to an illustrative embodiment of the invention. The source device **103** may be connected to a termination device **1710** associated with the flat wire **105**. With reference to FIG. **17**A, the source device **103** of the ASD **100** may include an electrical plug **1715** that is configured to be plugged into a corresponding socket **1720** of an electrical outlet **1705**. Additionally, the source module **110** of the ASD **100** may include one or more source termination points **1725** that are configured to be plugged into one or more corresponding termination plugs **1730** associated with the termination device **1710**. The flat wire **105** may be connected to the termination device **1710**, and each conductor of the flat wire **105** may be terminated at a respective termination plug **1730** of the termination device **1710**. The conductors of the flat wire **105** may be terminated at the termination device **1710** in an appropriate order, for example, in a G-N-H-N-G configuration. For example, a grounding conductor **220** of the flat wire **105** may be terminated first and then the other conductors of the flat wire **105** may be terminated in order until the other grounding conductor **225** is terminated. Given the symmetry of the flat wire **105** example described in this disclosure, the flat wire **105** should be terminated correctly regardless of which grounding conductor **220**, **225** is terminated first provided that a G-N-H-N-G configuration is used and that the flat wire **105** conductors are terminated in order starting with a grounding conductor **220**, **225**.

With continued reference to FIG. **17**A, when the ASD **100** is plugged into the electrical outlet **1705**, the source termination **1725** points will also be connected to the corresponding termination plugs **1730** of the termination device **1710**. When the ASD **100** is unplugged from the electrical outlet **1705**, the connection with the termination device **1710** will also be severed. Additionally, the termination device **1710** may be situated remotely from the electrical outlet **1705**, requiring the ASD **100** to complete the connection between the line side power source **115** and the flat wire **105**. Accordingly, the ASD **100** may test the flat wire **105** prior to the communication of an electrical power signal from the line side power source **115** to the flat wire **105**.

As shown in FIG. **17**A, the source termination points **1725** are male termination points and the corresponding termination plugs **1730** of the termination device **1710** are female termination points. However, as desired, the source device **103** may include female termination points and the termination device **1710** may include male termination points. Additionally, as desired, other suitable types of connections may be utilized between the source device **103** and the termination device **1710**. Additionally, the connections illustrated in FIG. **17**A only require the use of one socket **1720** of an electrical outlet **1705**. Accordingly, any remaining sockets of the electrical outlet **1705** may be free for use with other devices.

According to another aspect of the invention, the ASD **100** may include or incorporate one or more electrical sockets or extender outlets that permit standard electrical plugs to be plugged into the ASD **100**. FIG. **17**B is a schematic diagram of an ASD **100** that includes extender outlets, according to an illustrative embodiment of the invention. The ASD **100** of FIG. **17**B is illustrated as being plugged into an electrical socket, such as the electrical socket **1705** of FIG. **17**A, that is situated on a wall **1735**. As desired, the ASD **100** may include any number of extender outlets and the extender outlets may be situated on any surface of the ASD **100**. As shown in FIG. **17**B, the ASD **100** may include two extender outlets **1740**, **1745** on a peripheral surface of the ASD **100** that extends from the front of the ASD **100** to the front surface of the wall **1735**. The extender outlets **1740**, **1745** may be configured in such a manner that the female connections of the extender outlets **1740**, **1745** are situated in a horizontal manner relative to the floor or ceiling of a room. Accordingly, each of the extender outlets **1740**, **1745** may permit an electrical plug that includes a transformer to be inserted without contacting the wall **1735**. The extender outlets **1740**, **1745** may be configured in such a manner that their female connections are situated in any suitable, manner, for example, that of the standard electrical outlet **1705** of FIG. **17**A. Additionally, a destination device **117** may include one or more electrical outlets.

According to another aspect of the invention, the ASD **100** may be capable of supporting and monitoring more than one wire **102**. Multiple wires **102**, such as multiple flat wires **105** or multiple conventional wires **107**, may extend from the ASD **100** to separate destination modules **120** or separate loads **125**. Alternatively or additionally, more than one wire **102** may be disposed between the ASD **100** and a destination device **117** or the load **125**, as shown in FIG. **18**. Illustrated in FIG. **18** is a schematic diagram of a wire system **1801** including an ASD **100** that monitors two wires **102**, **1805** connected to the same destination device **117**, according to an illustrative embodiment of the invention. For example, as shown in FIG. **18**, both a primary wire **102** and a secondary wire **1805** may extend from the ASD **100** to a destination device **117**. If the ASD **100** detects a wire fault or miswire in the primary wire **102**, then the ASD **100** may maintain the relay **310** connected to the primary wire **102** in its open position, thereby preventing electrification of the primary wire **102**. The ASD **100** may then close a relay connected to the secondary wire **1805** and allow electrification of the secondary wire **1805** in order to power the load **125**. The secondary wire **1805** may be monitored by the ASD **100** in the same manner as the primary wire **102**. Additionally, the control unit **312** of the ASD **100** or, alternatively, a safety component of the ASD **100**, may provide an indication of the change to the secondary wire **1805** to a user. This indication may be any control action such as activating an LED that indicates the change by the ASD **100** to the secondary flat wire **1805**. Another control action that may be taken is the transmission of a message indicating the change by the ASD **100** to the secondary flat wire **1805**. The message may be transmitted to another ASD **100**, to a central hub or control panel, or to another destination, as will be explained in greater detail below.

According to another aspect of the invention, an ASD **100** or source device **103** containing an ASD **100** may be used in conjunction with more than one destination device **117**, and the destination devices may be connected in series. FIG. **19** is a schematic diagram of multiple destination devices **117***a-n* in a serial configuration being supported by a single source device **103**, according to an illustrative embodiment of the invention. As shown in FIG. **19**, a single source device **103** containing an ASD **100** may monitor a wire **102** that runs from the source device **103** to a series of destination devices **117***a-n*. Each of the destination devices **117***a-n* may be an electrical load such as an outlet assembly or receptacle. This type of configuration may also be referred to as an add-a-receptacle configuration or as a daisy chain configuration. Any number of ASD's and/or destination devices may be connected in series. Additionally, a variety of different types of wiring may be connected between any ASD and any destination device, such as flat wire **105** or conventional wire **107**. Furthermore, there is no requirement that the same type of wire be utilized throughout the series or daisy chain configuration.

As shown in FIG. **19**, a wire **102** may extend from the source device **103** through each destination device **117***a-n*. An input segment of the wire **102** may be terminated at each destination device **117***a-n* and then a new output segment of wire **102** may be used to connect the next destination device **117***a-n*. For example, a first segment of wire **102** may connect the source module **110** to the destination module **120** of the first destination device **117***a*, where the first segment of wire **102** is terminated. A separate segment of wire **102** may then connect the first destination device **117***a* to the second destination device **117***b*. This pattern may continue until the wire **102** reaches the last destination device **117***n*. Alternatively, a single segment of wire **102**, such as a single segment of flat wire **105** or a single segment of conventional wire **107**, may be used to connect all of the destination device **117***a-n*. Each destination device **117***a-n* may be connected to the wire **102** with a suitable terminal that connects each conductor of the wire **102** to the destination device **117***a-n*. Termination points within the destination module **120** and expansion module **122** of each destination device **117**, which are used to connect the wire **102** to the destination device **117**, may include terminal blocks, crimp-on terminals, plug and socket connectors, insulation displacement connectors (IDC), conductor penetration connectors (CPC), or any other electrical connector as desired in various embodiments.

Each destination device **117***a-n* may include a relay in communication with and controlled by the ASD **100** for passing the signal carried by the wire **102** on to the next destination device **117***a-n*. For example, the first destination device **117***a* may include a relay that passes the electrical power and/or signals carried by the wire **102** on to the second destination device **117***b*. The wire **102** may be relayed through each destination device **117***a-n*-**1** until the wire **102** reaches the last destination device **117***n*, at which point no relay is necessary. Optionally, each destination device **117** may include a DWI component **340** that is used to test the wire **102** extending from the destination device **117** to the next downstream destination device. The relays may be time delay relays, meaning that each of the relays may be actuated or closed after it receives power for a minimum period of time. The period of time that each relay needs to receive power before it is actuated may be a period of time that is sufficient for testing the next downstream segment of wire **102**, for example, approximately 375 milliseconds. Additionally, the period of time that each relay needs to receive power before it is actuated may be an adjustable period of time. As an alternative to a relay, each destination module **117***a-n* may include a control unit or other control logic that is in communication with the ASD **100**, and that is used to isolate a flaw in the wire **102**, as described in greater detail below with reference to destination device **117***a-n* that include relays.

Additionally, each of the destination devices **117***a-n* may be in communication with the ASD **100**, as described in greater detail below. While the ASD **100** is monitoring the wire **102**, if a miswire or fault is detected in the wire **102**, then the miswire or fault may be isolated by the ASD **100** by using the relays. As an example, before the relay **310** of the ASD **100** is closed, the ASD **100** may test the wire **102** for miswire or faults. The ASD **100** may first test the first segment of wire **102** that runs between the source module **110** and the destination module **120** of the first destination device **117***a*. If a miswire or fault is detected, then the ASD **100** may maintain the relay **310** in its open position and prevent electrification of the wire **102**. If no miswire or fault is detected in the first segment of the wire **102**, then the ASD **100** may test the combined first segment of the wire **102** and the second segment of the wire **102** that connects the first destination device **117***a* and the second destination device **117***b*. If a miswire or fault is detected, then the ASD **100** may prevent electrification of the wire **102** or it may transmit a signal to the relay of the first destination device **117***a* instructing the relay to remain open. The first segment of the wire **102** may then be electrified permitting a load connected to the first destination device **117***a* to receive power; however, none of the destination devices **117***b-n* connected down the line from the first destination device **117***a* will receive power. In this regard, a miswire or fault in the wire **102** may be isolated by the ASD **100**, and any destination devices **117***a-n* connected to the ASD **100** prior to the wire segment containing the miswire or fault are identified and may be permitted to receive power. The other wire segments may be prevented from receiving power. As another example, if the ASD **100** detects a miswire or fault in a wire **102** while the wire **102** is electrified, then the ASD **100** may open its relay **310** and de-energize the wire **102**. Then, the ASD **100** may use the method described in the example above to isolate the segment of the wire **102** in which the miswire or fault occurs, and the ASD **100** may allow electrification of the wire **102** up until the segment of the flat wire **105** at which the miswire or fault occurs. As another example, in order to avoid timing delays associated with incremental testing, an entire length of wire **102** (or more than a single wire segment) may be tested prior to electrifying the wire **102**. In order to accomplish this, the relays in each of the destination devices **117***a-n* may be closed and a test signal may be communicated through the wire **102** by the ASD **100**. If a miswire or fault is detected in the wire **102**, then the incremental method described above may be utilized to isolate the miswire or fault.

Alternatively, if each destination device **117***a-n* includes a DWI component **340**, then each destination device **117***a-n* may test the next downstream segment of wire **102** before that segment of wire **102** is electrified. The tests performed by the DWI component **340** of each destination device **117***a-n* may also be used to isolate a miswire or fault in the wire **102** and prevent the miswired or faulty segment of wire **102** and any downstream wire segments and/or electrical loads from receiving electrical power. As an example, the ASD **100** may first test the first segment of wire **102** that runs between the source module **110** and the destination module **120** of the first destination device **117***a*. If a miswire or fault is detected, then the ASD **100** may maintain the relay **310** in its open position and prevent electrification of the wire **102**. If no miswire or fault is detected in the first segment of the wire **102**, then the ASD **100** may allow the first segment of the wire **102** to be electrified. Then, the DWI component **340** of the first destination device **117***a* may test the second segment of the wire **102** that connects the first destination device **117***a* and the second destination device **117***b*. If a miswire or fault is detected, then the first destination device **117***a* may prevent electrification of the second segment of the wire **102** by opening the relay of the first destination device **117***a*. If, however, no miswire or fault is detected in the second segment of the wire **102**, then the first destination device **117***a* may allow the second segment of the flat wire **105** to be electrified. The destination devices **117***b-n* downstream from the first destination device **117***a* may contain the same functionality as the first destination device **117***a*. Accordingly, a miswire or fault in the wire **102** may be isolated by the ASD **100** and any destination devices **117***a-n* connected to the ASD **100** prior to the miswired or faulty segment of wire **102** are identified and may be permitted to receive power. The other wire segments are prevented from receiving power. As another example, if the ASD **100** detects a miswire or fault in a wire **102** while the wire **102** is electrified, then the ASD **100** may open its relay **310** and de-energize the wire **102**. Then, the ASD **100** and the destination devices **117***a-n* may use the method described in the example above to isolate the segment of the wire **102** in which the miswire or fault occurs, and the ASD **100** and the destination devices **117***a-n* may allow electrification of the wire **102** up until the segment of the wire **102** at which the miswire or fault occurs.

Additionally, in certain embodiments of the invention, any segments of the wire **102** that have been isolated may be retested by the ASD **100** and/or the associated destination devices **117***a-n* at one or more points in time that are subsequent to the time at which a fault or miswire was identified. In this regard, it may be determined whether a fault or miswire remains on the one or more isolated segments of the wire **102**. If it is determined that a fault is no longer present, then the one or more isolated segments of the wire **102** may be permitted to receive electrical power. However, if it is determined that a fault is still present, then the one or more isolated segments may remain isolated and not be permitted to receive electrical power. The one or more isolated segments of wire **102** may be continuously or periodically tested in order to determine whether a fault is no longer present. A wide variety of different time intervals may be utilized as desired in certain embodiments of the invention to periodically test the one or more isolated segments. For example, the isolated segments may be tested approximately every one (1) minute, approximately every 10 minutes, or approximately every one (1) hour. As another example, the wire **102** may be continuously monitored to determine whether a fault is no longer present.

Additionally, if multiple segments of wire **102** are used to connect each destination device **117***a-n*, then the ASD **100** may cause a switch in each destination device **117***a-n* to be toggled in order to route a signal transmitted over the wire **102** through a secondary wire segment rather than a primary wire segment, as described above with reference to FIG. **17**. Using the previous example prior to the electrification of the wire **102**, if a miswire or fault existed in a segment of wire **102** that connected the first destination device **117***a* and the second destination device **117***b*, then the ASD **100** may cause a switch in the first destination device **117***a* to be toggled in order to switch the segment of wire **102** that connects the first destination device **117***a* and the second destination device **117***b* to a secondary segment of wire **1805** rather than a primary segment of wire **102**. At this point, the ASD **100** and/or the destination devices **117***a-n* may resume testing of the wire **102** by testing the secondary segment of wire **102** that connects the first destination device **117***a* and the second destination device **117***b*.

FIG. **20** is a schematic diagram of a system in which multiple source devices **103***a-d* form a central device that monitors multiple wires **102***a-d* in a room, according to an illustrative embodiment of the invention. The monitored wires may be one or more of a wide variety of different wires, such as flat wires **105** and/or conventional wires **107**. Each source device **103** may contain an ASD **100**. As shown in FIG. **19**, more than one source device **103***a-d* may be assembled into a single device that is capable of monitoring multiple branches of wire **102***a-d* extending from the combined device. Accordingly, the combined device may form a central device that is capable of controlling multiple wire branches **102***a-d*. Each of the wire branches **102***a-d* may be terminated at a destination device **117***a-d*. For example, the combined source device **103***a-d* may be placed in, on, or near one wall of a room and separate wire branches **102***a-d* may extend from the combined source device to each wall of the room. The individual ASD's within the combined source device may then monitor one or more of the wire branches **102***a-d* extending from the combined device. Although the central device of FIG. **19** is depicted as a combination of source devices **103***a-d*, a single device may be utilized in accordance with certain embodiments of the invention to monitor multiple wire branches **102***a-d*.

FIG. **21** is a schematic diagram of a wire network **2100** that includes a network of source devices **103** monitored by a central hub **2105**, according to an illustrative embodiment of the invention. Each of the source devices **103** may include one or more ASD's **100** capable of monitoring wire branches **102** connected to the source devices **103**. The wire branches **102** may include one or more different types of wire, such as flat wire **105** and/or conventional wire **107**. A network may be established in which one or more electrical wires **2110**, which may be conventional wire **107** and/or flat wire **105**, are connected between the central hub **2105**, which may be associated with a common circuit breaker box, to each room in a building. Each of these electrical wires **2110** may be connected to a source device **103** in a separate room. Accordingly, each source device **103** may be used as a power center that services an entire room.

This method of wiring may be, for example, an inexpensive way to rewire a home using flat wire where in-wall renovation is not practical, such as in some older homes. Once an electrical wire has been extended from the central hub **2105** to a room, the flat wire **105** becomes an economical and feasible way to distribute power to each of the room's walls or to the room's ceiling or floor. Although flat wire **105** may be used in accordance with certain embodiments of the invention to distribute power within a room, other embodiments of the invention may utilize conventional wire **107** and/or other types of wiring to distribute power within a room. The source devices **103** may then facilitate the monitoring of these various types of wiring within the room.

The source devices **103** may act as a power center that services each room by providing a gateway between the electrical wire **2110** and the wire **102** branch circuits within the room. Each of the wire **102** branch circuits may be connected to one or more destination devices **117**, as previously described. Each of the source devices **103** shown in FIG. **21** may contain a single ASD **100** capable of monitoring one or more wire **102** branch circuits or, alternatively, each of the source devices **117** may contain more than one ASD **100** for monitoring wire **102** branch circuits, as described with reference to FIG. **20** above.

Within a room, each source device **103** may service any of the walls, ceiling, and floor with a wire **102** branch circuit. Each source device **103** may individually control the wire **102** branch circuits to which it is connected. Additionally, each source device **103** may communicate with branch circuit destination devices **117** over the wire **102** in order to monitor circuit safety and electrification status. As previously discussed, the destination devices **117** may include a relay, detection circuitry, and/or a control unit that is in communication with the source device **117** monitoring the wire branch circuit **102** to which the destination device **117** is connected. Accordingly, any segment of the wire network may be isolated and shut off if a flaw is detected in that segment. Additionally, each source device **117** may be surface mounted on a wall or mounted inside a wall within the room, or situated nearby.

Each source device **103** also may communicate with a central hub **2105**. The central hub is preferably located near the circuit breaker box or at least in the building. It also is possible, however, for the central hub **2105** to be situated remotely to the building. The central hub **2105** may collect data from each of the source devices **103** and provide safety and electrification status for all of the branch circuits **102** in the building. The central hub **2105** may also be surface mounted or mounted inside a wall.

If a wire **102** miswire or fault is detected on any given branch circuit, then either the central hub **2105** or the source device **103** controlling that branch circuit, or both, may render that branch circuit unusable and isolate it from the other branches. Alternatively a downstream destination device **117** connected to a source device **103** may render the miswired or faulty branch circuit unusable and isolate it from the other branches. In other words, that branch circuit may not be permitted to be electrified. In this manner, a miswired or faulty branch circuit may be rendered unusable while at least a portion of the other branch circuits are not affected. Therefore, a penetration of a wire **102**, such as flat wire **105** or conventional wire **107**, or a miswire of the conductors of a wire **102**, may only result in power loss in one branch of the wire network **2100**.

According to another aspect of the invention, the wire **102** may be used to communicate signals. These signals may be communicated between any device in a wire network or wire branch circuit over the wire **102**. Certain embodiments of the invention may communicate signals over flat wire **105** and/or conventional wire **107**. For example, with reference to FIG. **20**, a signal may be communicated between the ASD **100** in the source device **103** and any of the destination devices **117***a-n* over the wire **102**. Similarly, with reference to FIG. **21**, a signal may be transmitted over the wire **102** from one source device **103** to another source device **103** or between the central hub **2105** and one of the source devices **103**. Additionally, devices in a wire network or wire branch circuit may be in communication with one another through wires, conductors, or optical fiber external to the wire **102** or, alternatively, through wireless communication means, for example, via a wireless local area network.

A communications signal may be transmitted over any of the conductors of the wire **102**. A separate communications signal may be transmitted over each of the individual conductors of the wire **102**. A signal may be communicated onto one or more of the conductors of the wire **102** by a suitable excitation circuit, such as, the excitation circuit described above with reference to FIG. **9**B for flat wire **105** embodiments. The signal may then be identified and read from the one or more conductors of the wire **102** by a sense circuit, for example, the sense circuit described above with reference to FIG. **9**B for flat wire **105** embodiments. As an example utilizing flat wire **105**, the grounding conductors **220**, **225** of the flat wire **105** may be used for communicating signals. The signal communicated across the grounding conductors **220**, **225** may be a low voltage signal in the range of approximately 0.1 and 5.0 volts. Additionally, the frequency of a signal communicated across the grounding conductors **220**, **225** may be a frequency at or above approximately 1000 Hz. There is normally no voltage or current present on the grounding conductors **220**, **225**; therefore, the grounding conductors **220**, **225** may beneficially be used to transmit communications signals even when the flat wire **105** has been fully electrified. Similar to the grounding conductors **220**, **225**, a communications signal may be transmitted over the return conductors **210**, **215** of a flat wire **105**. The signal communicated across the return conductors **210**, **215** may be a low voltage signal in a range of approximately 0.1 to 5.0 volts. Additionally, the frequency of a signal communicated across the return conductors **210**, **215** may be a frequency at or above approximately 1000 Hz. A signal may be communicated across the conductors of the flat wire **105** while the flat wire **105** is electrified. As desired, a signal may include an appropriate identifier, for example, a signal header that may be utilized to identify the signal and, therefore, prevent false trips by one or more of the safety components of an ASD **100**.

Continuing with the example using a flat wire **105**, a communications signal may also be transmitted over the electrifiable conductor **205** of the flat wire **105**. The signal communicated across the electrifiable conductor **205** may be a low voltage signal at a voltage of approximately 0.1 to 5.0 volts. Additionally, the frequency of a signal communicated across the electrifiable conductor **205** may be at a frequency at or above approximately 1000 Hz. A signal may be transmitted over the electrifiable conductor **205** both when the flat wire **105** is electrified and when the flat wire **105** is not electrified. In accordance with the flat wire **105** used in conjunction with the present disclosure, an electrified flat wire **105** may carry a voltage signal of approximately 110-130 volts (for North America applications) or approximately 230-250 volts (for European applications) at a frequency of approximately 50-60 Hertz. A communications signal, however, may still be transmitted over the electrifiable conductor **205** using suitable power line carrier (PLC) or broadband over power line (BPL) technology. A PLC or BPL signal transmitted over the electrifiable conductor **205** may be at a voltage of approximately 0.1 to 20 volts. In one embodiment, the voltage of the signal transmitted over the electrifiable conductor **205** may be at a voltage of approximately 0.1 to 5 volts. Additionally, a PLC or BPL signal transmitted over the electrifiable conductor **205** may be at a frequency that is greater than approximately one megahertz (MHz). For example, the frequency may be in a range of approximately 2 to 20 MHz, although frequencies up to and greater than approximately 40 MHz may be used in conjunction with certain embodiments of the invention. Additionally, as discussed above, a signal may include an appropriate identifier.

In certain embodiments of the invention, one or more communications signals may be communicated over one or more of the conductors of a conventional wire, such as wire **107**. Communications signals may be communicated over the electrifiable conductor **250**, the return conductor **255**, and/or the grounding conductor **260** of a conventional wire **107** in a similar manner as that described above in the example using flat wire **105**. Additionally, in certain other embodiments of the invention, communications signals may be communicated over one or more conductors of other types of wiring that may be utilized in association with a source device **103**, an ASD **100**, and/or a destination device **117**.

According to another aspect of the invention, communications signals transmitted over one or more of the conductors of a wire **102** may be used to establish communication between devices that are connected by a wire **102**. For example, the communications signals may be used to establish communication between two ASD's **100**, between an ASD **100** and a destination device **117**, or between an ASD **100** and a central hub **2105**. Additionally, communication signals may be transmitted over the wire **102** by devices that are connected by the wire **102** according to a communications protocol. For example, the communications signals may be transmitted via a user datagram protocol (UDP), via a transmission control protocol (TCP), or via another suitable protocol as desired. Additionally, a communications signal may be used to establish a connection between two devices connected by a wire **102**. The connection established may be point-to-point connection or it may be some other type of connection, such as a peer-to-peer or local area network connection.

Accordingly, example embodiments of the invention can provide the technical effects of creating a system, method, and apparatus that facilitates the monitoring of electrical wire for wire faults, miswires, and/or abnormal conditions. Example embodiments of the invention may further control the electrification of the electrical wire based upon the monitoring. The electrical wire may be monitored prior to electrification, during electrification, and/or after electrification.

The invention is described above with reference to block and flow diagrams of systems, methods, apparatuses, and/or computer program products according to example embodiments of the invention. It will be understood that one or more blocks of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, respectively, can be implemented by computer-executable program instructions. Likewise, some blocks of the block diagrams and flow diagrams may not necessarily need to be performed in the order presented, or may not necessarily need to be performed at all, according to some embodiments of the invention.

These computer-executable program instructions may be loaded onto a general purpose computer, a special-purpose computer, a processor, or other programmable data processing apparatus to produce a particular machine, such that the instructions that execute on the computer, processor, or other programmable data processing apparatus create means for implementing one or more functions specified in the flowchart block or blocks. These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means that implement one or more functions specified in the flow diagram block or blocks. As an example, embodiments of the invention may provide for a computer program product, comprising a computer usable medium having a computer readable program code or program instructions embodied therein, said computer readable program code adapted to be executed to implement one or more functions specified in the flow diagram block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational elements or steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide elements or steps for implementing the functions specified in the flow diagram block or blocks.

Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, can be implemented by special-purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special purpose hardware and computer instructions.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which embodiments of the invention pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

That which is claimed:

**1**. A source device for use with electrical wire, the source device comprising:

a line side input configured to connect to a line side power source and receive an electrical power signal from the line side power source;

a wire connection configured to connect to an electrical wire;

at least one relay configured to control the communication of the electrical power signal onto the electrical wire; and

a control unit associated with a line side wire integrity component configured to identify a plurality of conductors associated with the line side power source, the plurality of conductors comprising at least one electrifiable conductor, at least one return conductor, and at least one grounding conductor, wherein the line side wire integrity component is further configured to determine whether the plurality of identified conductors are properly terminated at the line side input and to control the actuation of the at least one relay based upon the determination.

**2**. The source device of claim **1**, wherein the at least one relay and the control unit comprise an active safety device.

3. The source device of claim **1**, wherein the control unit is further configured to test the electrical wire for at least one of miswires, wire faults, or abnormal conditions and to control the actuation of the at least one relay based at least in part on the testing of the electrical wire.

4. The source device of claim **3**, wherein the control unit identifies a wire fault on the electrical wire, and

wherein the control unit is further configured to test the electrical wire subsequent to the identification of the wire fault and to determine whether the identified wire fault is still present on the electrical wire.

5. The source device of claim **4**, wherein the control unit is further configured to electrify the electrical wire if it is determined that the identified wire fault is no longer present on the electrical wire.

6. The source device of claim **5**, wherein the electrical wire is electrified by the control unit without receiving any user input.

7. The source device of claim **3**, wherein the control unit is associated with at least one reactive safety component that is utilized in the testing of the electrical wire.

8. The source device of claim **7**, wherein the at least one reactive safety component tests the electrical wire subsequent to the electrification of the electrical wire.

9. The source device of claim **7**, wherein the at least one reactive safety component comprises one or more of a group consisting of a ground fault circuit interrupter, an arc fault circuit interrupter, an over-current protection safety component, and a ground current monitoring safety component.

10. The source device of claim **3**, wherein the control unit is associated with at least one proactive safety component that is utilized in the testing of the electrical wire.

11. The source device of claim **10**, wherein the at least one proactive safety component tests the electrical wire prior to the electrification of the electrical wire.

12. The source device of claim **10**, wherein the at least one proactive safety component comprises a load side wire integrity component that is configured to communicate at least one test signal onto at least one conductor of the electrical wire, to monitor one or more of the conductors for one or more return signals, and to determine whether a miswire or wire fault exists based upon the one or more return signals.

13. An electrical wire system, comprising:

a source device configured to be coupled to a line side power source, wherein the source device comprises an active safety device and a first wire termination;

a destination device, wherein the destination device comprises a second wire termination; and

an electrical wire having a first end coupled to the first wire termination and a second end coupled to the second wire termination;

wherein the active safety device is configured to (i) identify a plurality of conductors associated with the line side power source, the plurality of conductors comprising at least one electrifiable conductor, at least one return conductor, and at least one grounding conductor, (ii) determine whether the plurality of identified conductors are properly terminated at the line side input, and (iii) control the communication of an electrical power signal from the line side power source to the electrical wire based upon the determination.



14. The electrical wire system of claim **13**, wherein the active safety device is further configured to monitor the electrical wire for at least one of miswires, wire faults, or abnormal conditions and, based upon the monitoring, to control the communication of the electrical power signal from the line side power source to the electrical wire.

15. A method for monitoring an electrical wire terminated between a source and a destination, the method comprising:

identifying a plurality of line side conductors connected to the source opposite the electrical wire, the plurality of conductors comprising at least one electrifiable conductor, at least one return conductor, and at least one grounding conductor;

determining, based at least in part on the monitoring, whether the plurality of identified conductors are properly terminated at the source; and

controlling communication of an electrical power signal from a power source to the electrical wire based at least in part on results of the determination.

16. The method of claim **15**, further comprising:

testing one or more conductors of the electrical wire for at least one of miswires, wire faults or abnormal conditions; and

controlling communication of the electrical power signal from the power source to the electrical wire based at least in part on results of the testing.

17. The method of claim **16**, wherein testing one or more conductors of the electrical wire comprises testing one or more conductors of an electrified wire, and further comprising:

identifying at least one wire fault or abnormal condition on the one or more conductors; and

in response to identifying at least one wire fault or abnormal condition, de-energizing the electrical wire by ceasing the communication of the electrical power signal onto the electrical wire.

18. The method of claim **17**, further comprising:

conducting additional testing on the one or more conductors of the electrical wire; and

determining, based at least in part on the additional testing, whether the identified at least one wire fault or abnormal condition is still present on the electrical wire.

19. The method of claim **16**, wherein testing one or more conductors of the electrical wire comprises testing one or more conductors of the wire prior to electrifying the wire, and further comprising:

identifying at least one wire fault or abnormal condition on the one or more conductors; and

in response to identifying the at least one wire fault or abnormal condition, preventing the electrification of the wire.

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